ANALYSIS OF STORM SURGE IMPACTS ON TRANSPORTATION SYSTEMS IN THE GEORGIA COASTAL AREA

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ANALYSIS OF STORM SURGE IMPACTS ON TRANSPORTATION SYSTEMS IN THE GEORGIA COASTAL AREA

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To my Family, my support, my encouragement, my love, my happiness

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LIST OF SYMBOLS AND ABBREVIATIONS

FWHA	Federal Highway Administration
GIS	Geographic Information System
NOAA	National Oceanic and Atmospheric Administration
EM	Electrical/Mechanical Damage Source
SC	Scour Damage Source
I	Impact Damage Source
D	Deck Damage Source
W	Wind Damage Source
WNW305i4	West North-West, Category 3, 5mph, High tide
WNW315i4	West North-West, Category 3, 15mph, High tide
WNW325i4	West North-West, Category 3, 25mph, High tide
WNW335i4	West North-West, Category 3, 35mph, High tide
WNW405i4	West North-West, Category 4, 5mph, High tide
WNW415i4	West North-West, Category 4, 15mph, High tide
WNW425i4	West North-West, Category 4, 25mph, High tide
WNW435i4	West North-West, Category 4, 35mph, High tide
WNW505i4	West North-West, Category 5, 5mph, High tide
WNW515i4	West North-West, Category 5, 15mph, High tide
WNW525i4	West North-West, Category 5, 25mph, High tide
WNW535i4	West North-West, Category 5, 35mph, High tide

SUMMARY

Many Climate Scientists believe that global warming will produce more extreme weather events such as tropical storms, hurricanes, intense rainfall, and flooding. These events are considered to be the most catastrophic natural events for transportation systems especially in coastal areas. Due to the severe damage from storm surge and flooding. Evaluating the magnitude of possible storm surges and their impacts on transportation systems in coastal areas is fundamental to developing adaptation plans and impact assessments to mitigate the damage.

This thesis focuses on existing transportation systems in the Georgia coastal area that could be affected by several storm surges. An existing storm surge model is used to estimate the storm surges and the surge heights based on the category, direction, and forward speed of a storm. The ground elevation of the ports, interstates, state roads, railroads, and the principal airports on the Georgia coast are identified through a GIS analysis using the national elevation data set. Having the storm surge elevation and the elevation of the existing infrastructure, a GIS study is performed to identify those parts of the transportation system that will be affected by each type of storm giving results such as the length or sections of transportation assets under or above the surge elevation. A literature review of storm surge, rising sea levels, and their impacts on coastal bridges, roads, airports, ports, and railroads is presented in the thesis. Also, a description of the software used to analyze and estimate the impacts of climate change on transportation systems is described.

The study shows that several sections or segments of roads and railroads and other assets will be under water, especially with category 3, 4, and 5 storm surges. The transportation assets affected by the different possible storms are shown on 2D visualization maps. Also, the results are reported in charts and tables that contain the storm information and the length of road, interstates, and railroads under water.

This thesis provides useful information to the transportation agencies, ports, and other agencies, companies, or departments dependent on Georgia coastal transportation systems.

CHAPTER 1

INTRODUCTION

Considering the infrastructure impacts caused by storm surges and the identification of vulnerable assets is crucial for the engineering design of new transportation infrastructure and the adaptation of existing systems. These impacts depend on the magnitude and duration of the storm surge. The magnitude of the storm surge depends, in turn, on the landfall direction, category, forward speed, and initial tide levels of the hurricane. In the United States, hurricanes have had significant impacts on transportation systems. To illustrate, many transportation facilities were damaged by the storm surges associated with Hurricane Ike (2008), Hurricane Wilma (2008), Hurricane Katrina (2005), and Hurricane Ivan (2004) [4]. Recently, roads and railroads were severely damaged by the storm surge of Hurricane Irene (2011) in New York. The Georgia coast has experienced hurricane events in the past due to its geographic location, and with the likely increase in frequency of extreme weather events in this century, the Georgia coast will likely be exposed to more severe hurricane events [8]. Storm surge generates flooding that would not only affect transportation facilities but affects the ultimate purpose of transportation systems, the mobility of people and goods.

The objective of this study is to analyze the storm surge impacts (generated by different types of hurricanes) on the transportation system in the Georgia coastal area. For this study the impacts are measured by the length or sections of the transportation facilities affected by a storm surge (infrastructure under or above the surge elevation).

The study starts with a literature review that provides information about storm surge and its impacts on transportation systems. The following chapter describes the methodology, data sources, and the different software utilized for the analysis. Chapter 4 describes the asset types in the transportation system on that part of the Georgia coast chosen for the analysis. The results of the analysis are provided in Chapter 5. These results are summarized by storm and by county. Chapter 6 provides a brief and general summary of the results from chapter 5 and provides charts and discussions of the results. Finally, the conclusions of the study are reported in chapter 7.

CHAPTER 2

LITERATURE REVIEW

This chapter provides the reader with a general knowledge of the impacts of storm surge on transportation systems. A literature review indicates the relevance of a storm surge study and the kind of damage that the transportations system of the Georgia coast is subject to during a hurricane event. The focus is on hurricanes, storm surge, climate change, and rising sea levels.

2.1 Hurricanes, Storm Surge, and Sea Level Rise

2.1.1 Hurricane Definition and Statistics

A hurricane is the most severe type of tropical cyclone with winds greater than 74 miles per hour (119 kilometer per hour). The Hurricane Research Division of the Atlantic Oceanographic and Meteorological Laboratory defines a tropical cyclone as a low pressure system commonly generated in the tropical region of the globe [1]. This weather event is accompanied by numerous thunderstorms that produce violent winds, high waves, torrential rain, and damaging storm surge. Hurricanes are categorized according to their intensity using the Saffir-Simpson hurricane wind scale. The 1 to 5 wind scale provides information about wind speed and types of damage. The types of damage and impacts are described in a summarized scale table according to: (1) Winds, (2) Damage, (3) People, Livestock, and Pets, (4) Mobile Homes, (5) Frame Homes, (6) Apartments, Shopping Centers, and Industrial Buildings, (7) High-rise, Windows, and Glass, (8) Signage, Fences, and Canopies, (9) Trees ,(10) Power and Water, and (11)

Hurricane Examples. In general, damage rises by about a factor of four for every increase in hurricane category [2].

Category 1 Hurricane, the lowest category, has winds of 74 mph or 119-153 km/hr. Summary: "*Very dangerous winds will produce some damage " Example:* Hurricane Dolly (2008) in South Padre Island, Texas [2].

Category 2 Hurricane has sustained winds of 96-110 mph or 154-177 km/hr. Summary: "*Extremely dangerous winds will cause extensive damage". Example:* Hurricane Frances (2004) on coastal portions of Port St. Lucie [2].

Category 3 Hurricane has sustained winds of 111-130 mph or 178-209 km/hr. Summary: "*Devastating damage will occur"*. Example: Hurricane Ivan (2004) on coastal portions of Gulf Shores, Alabama [2].

Category 4 Hurricane has sustained winds of 131-155 mph or 210-249 km/hr. Summary: "*Catastrophic damage will occur". Example:* Hurricane Charley (2004) on coastal portions of Punta Gorda, Florida [2].

Category 5 Hurricane, the highest category, has sustained winds greater than 155 mph or 249 km/hr. Summary: "*Catastrophic damage will occur".* Example: Hurricane Andrew (1992) coastal portions of Cutler Ridge, Florida [2].

(For more information about the hurricanes categories see appendix A Saffir-Simpson Hurricane Wind Scale "Category Storm Table")

The Saffir-Simpson scale indicates that the higher the intensity of the hurricane, the more severe the damage will be. However, depending on where and when the storm strikes, the impacts of a low category hurricane can be as severe as the impacts of a high category hurricane [3]. For example, the Blake, E., C. Landsea, et al Technical Memorandum NWS NHC-6 reports that Category 1 Hurricane Diane that hit the northeastern U.S. in 1995 was the seventeenth deadliest Hurricane since 1900 [4].

On August 2011, NOAA published a technical memorandum called, "The deadliest, costliest and most intense United States tropical cyclones from 1851 to 2010 (and other frequently requested hurricane facts)" that presented statistics on United States hurricanes and tropical cyclones [4]. The following information is summarized from this report. There were 284 hurricanes that struck the U.S from 1851 to 2010, where 96 of them were Category 3, 4, and 5. In the last two decades (1991-2010), a total of 33 hurricanes hit the U.S. From 1995 to 2010, the average number of tropical storms and hurricanes was 14.8 tropical storms and 7.9 hurricanes (3.9 major hurricanes) per year [4]. It was also observed that the 30 costliest mainland Unities States tropical cyclones (1900-2010) oscillated from Category 1 to 5, where the majority of the hurricanes were category 3 (total count 14) and category 2 (total count 7). Ranks 9, 17, and 28 of this list were Category 1 hurricanes. From 1851 to 2010, the Georgia coast had two of the most intense hurricanes to strike the U.S. (rank 43/65 and rank 62/65). Moreover, 32 hurricanes made landfall in Georgia, 23 in coastal areas and only 9 inland. The statistics of this memorandum show that in the state of Georgia, major hurricanes are more likely to strike in the months: August, September, and October [4].

2.1.2 Storm Surge

The National Hurricane Center defines storm surge as a rise in the ocean generated by the strong winds of a tropical cyclone when the ocean water is pushed toward the shore. This rise of water is generated over and above the predicted astronomical tide [5]. The storm tide, water level rise, is obtained by the combination of storm surge and the astronomical tide. This level can be several feet higher if the hurricane makes landfall at high tide level. If the storm surge concurs with normal high tide, the storm tides can reach 20 feet or more [5].

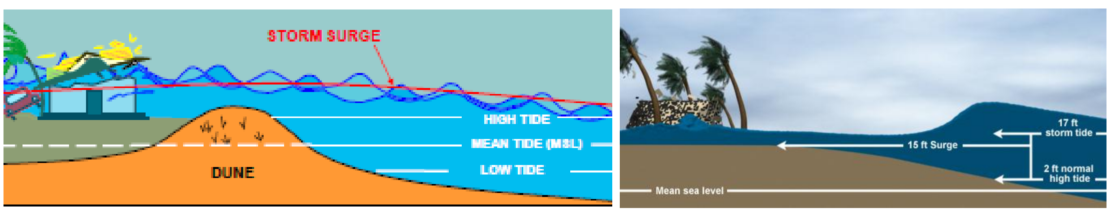


Figure 2.1: Tide with Storm Surge Level and Storm Tide (Image from NOAA sources [5][6])

The storm surge can be estimated by subtracting the normal high tide level from the storm tide. The storm surge is directly proportional to the intensity of the hurricane. The intensity of the storm surge depends essentially on the geography of the coast and its bays and the flooded topography. Jewell, B. (2006) states that the continental shelf and the shoreline elevation influence the inland storm surge elevation produced by a hurricane event [7]. He also states that areas with a steeper continental shelf will not have as much surge inundation. After a hurricane makes landfall, the storm surge can be 50 to 100 miles wide [3]. To illustrate, Category 3 Hurricane Katrina (2005), Category 3 Hurricane Opal (1995), and Category 2 Hurricane Ike (2008) generated storm surges of 25 to 28 feet, 24 feet, and 15- 20 feet, respectively [5].

The storm surge is the most deadly and destructive aspect of a hurricane. Bays are likely to have the highest storm surge. A hurricane can generate at least 6 to 12 inches of rainfall. [3] Therefore, the storm surge combined with the heavy rain can cause massive flooding in coastal areas. In addition, wave forces may increase the damage produced by the storm surge.

2.1.3 Literature

Several climate change studies have attributed global warming to the excessive accumulation of greenhouse gases in the atmosphere. Therefore, human action that generates emissions such as burning of fossil fuels (coal, oil, and gas) are considered to be a major cause of global warming. Currently, many efforts have been made to reduce and control greenhouse emissions; these efforts will likely continue in the future. The control and reduction of carbon dioxide emissions would lessen global warming, reducing the magnitude and the pace of climate change. However, in spite of efforts to control climate change, changes are still expected for the future due to the concentration of greenhouse gases that already exist in the atmosphere [9].

Scientists believe that global warming will be greater over this century than it was over the last century. The USGCRP scientific assessment "Global Climate Change Impacts in the United States" provides information about climate change and the impacts on the United States [9]. The following information was obtained and summarized from this source. Since 1900, the global average temperature has risen by about 1.5ºF and is expected to increase another 2 degrees to 11.5ºF by 2100. The average U.S. winter temperatures in the Midwest and Northern Great Plains have increased more than 7ºF over the last 30 years. This assessment also states that the U.S. average temperature is very likely to rise more than the global average over this century. In the U.S., drier conditions in the Southwest and Caribbean are expected to increase in this century. Due to the temperate rise, more precipitation will fall as rain and less as snow during the winter season and the ice melt on rivers and lakes will take place earlier in the spring season. The amount of rain precipitation has increased an average of about 5 percent over the last 50 years and the amount of rain in the heaviest downpours about 20 percent over the past century. Heavy precipitation, earlier snowmelt, and rising sea levels among other weather events will increase the incidents of severe flooding and erosion. In addition to flood events, water quality problems are likely to be amplified by climate change.

In coastal areas, more intense hurricanes with related increases in wind, rain, and storm surges (eg. Category 4 and 5 hurricanes) are predicted to occur this century. Although predictions indicate stronger hurricanes in the future, it is uncertain that these hurricanes could have increased chances of landfall.

In general, global warming will continue producing climate changes such as heat waves, regional droughts, frequency and severity of heavy rainfall, rising temperature and sea level, severe flooding events and subsequent erosion, lengthening growing seasons, alterations in river flow, rapidly retreating glaciers, earlier snowmelt, and more intense hurricanes. All these events are projected to grow affecting water, energy, agriculture, human health, transportation systems, infrastructures, and ecosystems even more than currently. These impacts and their severity vary from region to region. [9]

2.1.3.1 Sea Levels and Hurricanes - Globally and in the Southeast Region of the U.S

Sea level rise and the increase of the intensity of hurricanes in U.S. coastal areas will increase the risk of flooding and erosion, having significant impacts on transportation infrastructures, energy, and other property in coastal areas. It is expected that in this century, hurricanes will be more intense and will have higher rainfall rates (about 20% higher) than current hurricanes [10]. The Geophysical Fluid Dynamics Laboratory/NOAA report, "Global Warming and Hurricanes," states that a new modeling study projects an increase in Atlantic Category 4 and 5 hurricanes in this century, but is believed to be more recognizable after mid-century [10]. This increase in hurricane category would increase the level of damage to coastal areas. This report also states that the annual number of tropical storms globally will either decrease or remain essentially unchanged. However, some studies state that there is low confidence in this projection [11]. In the Atlantic region of the U.S., the damage potential of hurricanes has increased since 1970. Due to this progressive increase in hurricane power, an increase of average summer wave heights has been observed in the Atlantic region since 1975 [8].

Thieler, R., E. Hammar-Klose, et al. projected that in the next century the global average sea level will rise between 0.6 to 2 feet (this projection does not include Greenland and Antarctic ice sheet melt) [12]. They also state that sea level rise is not uniform around the world; therefore each region has a different project rise level. For example, the mean sea level trend of New Jersey is 3.99 millimeters/year and for Virginia (Chesapeake Bay Bridge Tunnel) the mean sea level trend is 6.05 millimeters/year [12]. The Geophysical Fluid Dynamics Laboratory/NOAA report states that the Southeastern coastal zone may have a rapid acceleration in the rate of increase in sea-level rise [10].

The combination of hurricane storm surge and projected sea level rise due to global warming will increase the vulnerability of flooding events in coastal areas [11]**.** Because sea levels are predicted to rise, an increase coastal inundation is also projected to happen even with a no increase in the intensity of tropical cyclones [12].

2.1.3.1.1 Georgia Coast Sea level Rise and Vulnerability Rating

NOAA's State of The Coast website provides mean sea level trend information for different stations along the U.S. coast with a 95% confidence level [14]. For the Georgia coast, station "8670870 Fort Pulaski" reports: "the mean sea level trend is 2.98 millimeters/year with a 95% confidence interval of +/- 0.33 mm/yr based on monthly mean sea level data from 1935 to 2006 which is equivalent to a change of 0.98 feet in 100 years"

NOAA State of The Coast also provides vulnerability to sea level rise interactive maps for the U.S. coasts. The following map and information of the U.S. and Georgia coasts are obtained from this source.

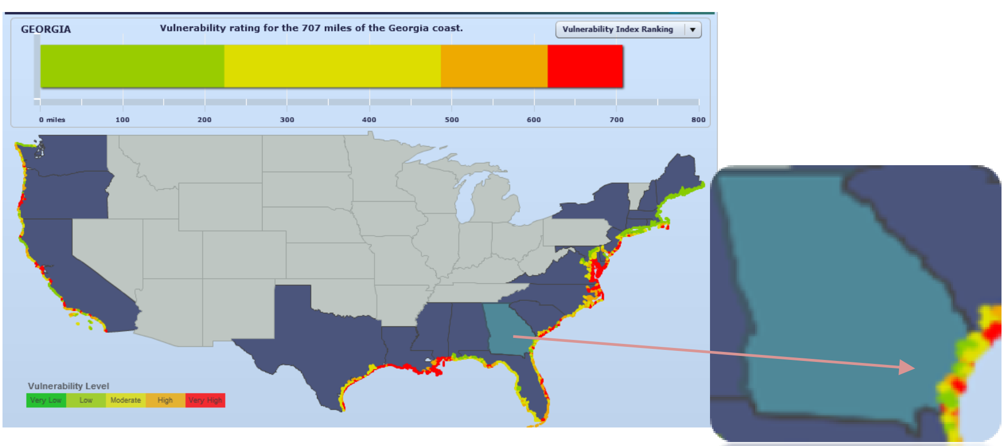


Figure 2.2: Vulnerability Index Ranking Map for 707 miles of the Georgia Coast [14]

Figure 2.2 shows the vulnerability of the U.S. coast (focus on the Georgia coast) with changes to future sea levels. The color-coded upper bar in the map shows the number of coastline miles at specific vulnerability levels for the coast of Georgia. For the Georgia coast there are: 223 miles of low vulnerability (31% of the Georgia coastline); 263 miles of moderate vulnerability (37% of the Georgia coast line); 129 miles of high vulnerability (18% of the Georgia coast line); and 90 miles of very high vulnerability (12% of the Georgia coast line).

Note: The coastal vulnerability calculation for a particular section of the U.S coastline is based on the vulnerability value due to sea level rise of six physical variables: geomorphology, shoreline erosion and accretion rates (m/yr), coastal slope (percent), rate of relative sea-level rise (mm/yr), mean tidal range (m), and mean wave height (m). The vulnerability value of each variable is assigned based on the potential magnitude of its impact on the coast as sea level rises [13].

2.2 Hurricanes, Storm Surge, Flooding Impacts on Transportation.

As mentioned earlier, climate changes increase hurricane intensity and sea level rise. Hurricanes can cause significant damage to transportation systems due to heavy rainfall, storm surge, winds, and the high waves that are generated during a hurricane. The combination of sea level rise, storm surge, and subsequent floods will increase the risk to major costal roads, bridges, airports, railroads, and ports. Heavy rainfall may cause landslides and slope failures that could damage road and rail infrastructure. Considering infrastructure impacts caused by storm surge is crucial for the engineering design of new coastal transportation projects and adaptation of the existing infrastructure.

Because transportation systems are vital for the economy, safety, and the quality of life of a region/country, the hurricane impacts on the transportation system will have a broader effect than simply a disruption of mobility also affect these areas [15]. For example, flooding caused by the storm surge and rainfall can produce interruptions and delays in road, rail, and air transportation affecting the circulation of goods and people/services. In addition, delays in road and rail transportation contribute to inefficient fuel use generating more emissions and therefore reduced air quality [15].

2.2.1 Roads and Railroads

Coastal roads and railroads are often affected by storm surge, flooding, flash floods, and washouts produced by a hurricane event. Such as extreme weather event affects mobility, accessibility, safety, and other aspects of the road and rail transportation system [16]. Floods can make segments of the road or tracks impassable affecting the mobility of goods and/or people.

2.2.1.1 Damaged Rail, Tropical Storm Irene 2011

If surge inundates railroad track, the scour generated by rapid water flow can remove track ballast, the sub-base, and even the earth subgrade. This material washout can produce substantial damage to the track structure. Flash floods can lead to washouts of segments of railroad tracks, which may cause train derailments. Bridges, signals, and power and communications systems of the railroad can also be damaged by the storm.

In August 2011, due to heavy rainfall, Tropical Storm Irene caused significant flooding to the areas near the lower Hudson Valley of New York. The storm produced heavy impacts on a 14 mile section of the Metro-North railroad at the Port Jervis Line

[17]. The Metro-North Railroad assessment "Tropical Storm Irene Condition Assessment of Port Jervis Line from MP31 to MP 45" provides information about the damaged railroad observed in the field [17]. This is a good example of how tropical cyclones affect railroad systems. The summary of the most significant damages that occurred to the Metro-North railroad included:

- Material Loss: Washouts produced by the heavy rain displaced and removed 90,000 cubic yards of track bed material with the ballast. The ballast became contaminated with all the debris carried from the storm water and could not be used again as base material. In some sections of the railroad, the rapid waters generated by the storm inundated the rail tracks scouring the track ballast, sub-base, and earth subgrade. Scours were found up to seven feet in depth.
- Track and Tie Damage: Because the water removed the sub base, it caused the tracks and ties to twist and bend damaging the track structure. Approximately 5000 linear feet of track structure were damaged.

Figure 2.3: Port Jervis Rail Damaged by Tropical Storm Irene. (Image from: AECOM [17])

Power and Communication System Damage: Many signal and communications cables became exposed because of the washout. Water infiltrated circuit controllers, switch machines, and battery wells along the fourteen miles of track.

- Other Damage: The embankment of ten major tracks sections was entirely removed by the washout resulting in suspended rails and ties above the eroded subgrade. Eight bridges were damaged. Damages included abutment scour and erosion.

Figure 2.4: Port Jervis Rail Embankment Completely Removed. (Image from: AECOM [17])

2.2.2. Road Damage and Highway "Overwash"

Roads located near the shore are exposed to coastal wave attack, surge, and erosion that can deteriorate the road structure [18]. Also, during a hurricane event, some roads can become flooded by the storm surge generating partial or total structure damaged [19]. Generally, roads near the shore have a low elevation and in some cases the storm surge elevation surpasses the road elevation and as a consequence, inundation of the road. To illustrate, Figure 2.5 shows the road damage due to the storm surge of Hurricane Ivan in 2004. The storm surge was almost 11 feet and the road pavement elevation was about 8 feet [18].

Figure 2.5: Road Pavement Damaged by Hurricane Ivan. (Image from: FHWA [18])

2.2.3 Pavement Damage Mechanism

The Federal Highway Administration publication FHWA-NHI-07-096,"Highways in the Coastal Environment" explains the process of pavement damage and provides examples [18]. The following information is a summary of the most relevant information found on highway overwashing in this publication.

When roads are subjected to "overwash", there are three main mechanisms that damage road pavement. They are: direct wave attack, parallel flow, and weir-flow mechanism. The direct wave attack takes place at the seaward shoulder of the road. The parallel flow mechanism is the flow that goes parallel to the road and moves to lower places in the road as the storm surge retreats. Late in the storm, some portions of the embankment are lower due to breaching or failure. The flood water held by the embankment will flow laterally to this low spot scouring the foundation material along the shoulder and causing damage or failure. The weir-flow damage mechanism happens when the surge elevation exceeds the elevation of the crown of the road and the water flows across the road, which then descends towards the landward shoulder of the road.

The flow (super-critical flow) down the landward shoulder scours the shoulder material. When the scour reaches the edge of the pavement, a hydraulic jump is produced by water flow crossing over the edge of the pavement causing pavement damage. This mechanism also occurs in the seaward shoulder of the road later in the storm as the surge returns to the sea. [18]

Many pavement damages observed after hurricane events such as Hurricane Ivan (2004), Tropical Storm Cindy (2005), and other small storms in 2005 were caused by weir-flow. The FHWA publication states that this mechanism was studied by the University of South Alabama and Texas A&M University [18]. The test performed in this study shows that the weir-flow damage mechanism can occur with only a small depth of water flowing across the road. Also, the study shows that waves moving across the road due to the storm surge exacerbates the weir-flow damage mechanism. Because flow velocity is increased with wave formation, scour on the descending area of the shoulder is increased as well. For example, in New Orleans during Hurricane Katrina, the downstream erosion caused by the overtopping waves of the storm surge caused the failure of embankments on some roads. [18]

2.3. Bridge Scours and Wave Forces in Coastal Environments

Since most highways, roads, and railroads in coastal areas utilize bridges in their design, an analysis of storm surge impacts on these structures is a vital area of consideration. Over 36,000 bridges are located within 15 miles of the coastline in the United States [18]. Coastal bridges are affected by storm surge due to the change in water elevation and the wave forces produced during the storm. The most common problems detected in bridges and produced by a storm surge are the scour, waves scour, and the wave forces on bridges decks. Several studies have found that scour is one of the most common reasons of bridge failures in the United States. Other problems detected in coastal bridges include increased concrete spalling and lateral loads on pilings. These problems are not going to be discussed in this section because these problems are not related to bridge failure during a storm surge.

For the design of new bridges and the inspection of current bridges in coastal areas, it is necessary to have the participation of coastal engineers. Coastal bridges require different consideration from riverine bridges, including consideration of wave forces (hydrodynamic loads from waves and tidal currents) and processes unique to the coastal environment. The design and analysis of coastal bridges are influenced by the size, orientation, and potential surge and wave effects [19]. This section will provide a brief description of the different types of coastal bridges and the definition and description of the different scours that can affect coastal bridges. Also, this section will provide information about wave forces and their effects on bridge decks. The information contained in this section is a summary of the findings of three FHWA publications: *"Tidal Hydrology Hydraulic and Scour at Bridges", "Evaluating Scour At bridges", and "Highways in The Coastal Environments*" [18][19][20].

2.3.1 Costal Bridges

Coastal bridges are defined by their location within the coastal area. There are four types of such bridges: bridges at inlets, bridge causeways, bridges tidal arms/ embayment, and river mouth bridge crossings.

Bridges at inlets are located at the entrance of a bay, which is where a bay and the ocean meet. The FHWA states that there are over 600 tidal inlets in the U.S. and many of these have bridges across their throat. The Golden Gate Bridge is an example of a bridge at an inlet. [18]

Bridge causeways refer to bridges or arrangement of bridges and elevated embankments that connect coastal and barrier islands, and peninsulas to the mainland. These bridges usually serve as an evacuation route during storm events. [18]

Bridges spanning tidal arms / embayments are located on tidal arms or embayments (interior water bodies or a distance upstream on an open bay or estuary). These bridges are more likely to be affected by wave action and wave transformation because they are in open water. To illustrate, most of the bridges affected by Hurricanes Ivan and Katrina were bridges spanning tidal arms/embayments. [18]

River mouth bridge crossings are located mostly in hills and mountains extending to the shoreline, which often result in a narrower floodplain. The FHWA states that there are several bridges crossing at or near the entrances of smaller rivers along the West Coast of the United States. [18]

2.3.2 Bridge Scour

There are several studies of the evaluation and estimation of scour at bridges. The FHWA publication called "Evaluating Scour at Bridges" contains a guideline for the design of new bridges to resist scour, evaluation of existing bridges for vulnerability to scour, and inspection of bridges for scour [20]. The authors of this publication define bridge scour as "the result of the erosive action of flowing water, excavating and carrying away material from the bed and banks of streams and from around the piers and abutments of bridges". In order to evaluate scour potential at bridges, engineers need to study the type of material/soil around the piers and abutments because different materials scour at different rates [20]. For example, foundations on rock or rock formations with few discontinuities are greatly resistant to scour during the lifetime of a bridge. Unlike riverine environments, coastal environment scour results from flow not only in one direction. Coastal environment scours occur in two directions (downstream and upstream) [20]. The types of scour that occur at coastal bridges are general scour, local scour at the piers or abutments, and wave scour.

Clear-water and live-bed scour are conditions of local and general scour. The FHWA publication, "Evaluating Scour at Bridges", provides the definitions of clear water and live-bed scour [20]. Clear Water: "Clear-water scour occurs where there is no transport of bed material upstream of the crossing or encroachment or the material being transported from the upstream reach is transported through the downstream reach at less than the capacity of the flow". Flow obstructions such as pier and abutment create vortices that moved the bed material around these structures (obstructions). Live-bed: "Live-bed occurs when there is transport of bed material from the upstream reach into the crossing or encroachment". Since clear water scour occurs in coarse-bed material streams, its maximum scour depth is reached over a longer period of time than live-bed scour [20]. During a flood event, three stages of scour occur in bridges over streams with coarse-bed material. First the bridge is subjected to clear-water scour at low discharges followed by live-bed scour at higher discharges. As the discharge decreases, the bridge is again subjected to clear-water scour. [20]

2.3.2.1. General/ Contraction Scour

General scour is defined as the general decrease in the elevation of the bed across the bridge opening [20]. The most common general scour is contraction scour. The decrease in the channel width caused by a natural narrowing of the stream channel or by the bridge, decreases flow and increases velocity, which results in a contraction scour at the bridge [20]. It is called contraction scour because there is a contraction of the flow, which results in the removal of material from the bed and banks across all or most of the channel width. General scour may be cyclic and/or related to the passing of a flood. It means that there can be an increase and decrease of the stream bed elevation during the passage of a flood. The formation of contraction scour at coastal bridges depends on the location and orientation of the bridges and embankments [18].

Hydraulic literature sources provide equations to calculate contraction scour based on the live-bed or clear-water. According to the HEC-18 report, the equations for local scour contained in it can be applied to coastal bridges. For coastal bridge scour calculation, it is important to include the design conditions of velocities created by hurricane or storm surge. Because the surge can produce extreme velocities that could produce a very deep scour [18]. However, this high velocity condition created by the surge has a short duration and ultimate scour may not be reached [20]. Due to the fact that the HEC-18 equations were developed for ultimate scour conditions, it is stated that these equations may be unduly conservative for surge [19].

2.3.2.2 Local Scour at the Piers or Abutments

Local scour in coastal bridges is caused by the formation of a vortex at the base of the pier or abutment [20]. As mentioned before, the vortex results from the obstruction of the flow ,and subsequently its acceleration around the nose of the pier or abutment. The vortex removes material from around piers, abutments, spurs, and embankments. Local scour can be either clear-water or live-bed scour. In coastal environments the scour hole can be formed around the entire pier [19]. The scour is intensified by rubble accumulation, which is common during coastal storm events. Local scour is cyclic because the scour hole that develops during the rising stage of a flood refills during the falling stage [20]. For live-bed local scour, scouring ceases when the equilibrium between bed material inflow and outflow is reestablished. For clear-water the scouring will cease if the vortex shear stress and sediments critical shear stress at the bottom of the scour hole are equal [20].

There is an additional vortex (vertical vortex) that occurs downstream of the pier called “wake vortex” [20]. This type of vortex also removes material from the pier base region, but as the distance of the downstream of the pier become larger the intensity of this vortex decreases very fast. Consequently, there is regular deposition of material immediately downstream of a long pier.[20]

Ten factors affect the magnitude of local scour depth at piers and abutments. These factors were taken and summarized from the FHWA publication “Evaluating Scour at Bridges” [20].

1. Velocity of the approach flow: The greater the velocity, the deeper the scour.

2. Depth of flow: the scour depth can be increase by a factor of 2 or greater if there is an increase in the flow depth. With abutments. Depending on the geometry of the abutments the scour depth can increase by a factor of 1.1 to 2.15.
3. Width of the pier: The scour depth can increase if the pier width increases. There is a limit to the increase in scour depth as width increases.
4. Discharge intercepted by the abutment and returned to the main channel at the abutment: Flume studies have shown that the scour can increase if there is an increase in the projected length of an abutment into the flow.
5. Length of the pier if skewed to flow: if the pier is aligned with the flow it has no significant effect on local scour.
6. Size and gradation of bed material: Bed material in the sand-size range has little effect on local scour depth. Particles such as coarse gravels, cobbles, or boulders in the bed material may armor the scour hole.
7. Angle of attack of the approach flow to a pier or abutment: it has a significant effect on local scour. Abutment scour is reduced when embankments are angled downstream and increased when embankments are angled upstream.
8. Shape of a pier or abutment: Streamlining the front end of a pier reduces the strength of the vortex; therefore reducing the scour depth.
9. Bed configuration: Bed configuration affects the scale of local scour. Flow velocity sediment transport are affected by the type and change in bed configuration.

10. Ice formation or jams and debris: Ice and debris can change shape and increase the width of the piers and abutments causing the flow to drop downward against the bed. Ice formation or jams and debris can increase local and general scour.

2.3.3 Wave Scour

Wave scour is related only to coastal structures. Due to the presence of wave forces, it is necessary to consider the wave breaking (occurring during a storm surge) into the scour calculation process because these forces would exacerbate the scour [18]. Research on wave scour has suggested that wave scour is less than general local scour. However, it is also stated that the combination of braking waves and ocean current would increase the scour rate and total scour depth [18]. The following wave scour examples are obtained from the FHWA publication “Highways in the Coastal Environment” [18]. During Hurricane Katrina the US-90 Biloxi Bay bridge became subject to waves and a storm surge of approximately 15 feet. A scour hole of significant size and extent was formed in the vicinity of a pier section (see figure 6). Another example is the scour along the piers on the bridge in the Indian River Inlet. The bridge has been progressively experiencing scour since 1930 and by 2000 the scour exceeded depths of 100 feet. Also, after the passage of two successive tropical storms in 2005, the Florida causeway experienced wave scour episodes. The waves struck the causeway abutments and bridge piers causing a scour hole of over 30 feet in depth. [18]

Figure 2.6: Wave Scour hole Formed by Hurricane Katrina (Image from FHWA [18])

2.3.4 Wave Forces in Coastal Bridges

Wave forces of a storm surge during a hurricane event can generate partial or complete damage in bridges. To illustrate, the principal cause of the bridge damage caused by Hurricanes Katrina and Ivan was the wave loads that the bridges experienced during these events. Because the storm surge raised the water level, the waves' forces struck the simple-span bridge decks [18]. The waves produced uplift and horizontal forces on the bridge deck that exceeded "weight" forces of the decks and the small lateral resistance provided by the connections, thus causing the deck's failure [18].

The FHWA publication "Highways in the Coastal Environment" describes two kinds of wave forces: the varying force and the impact force [18]. The varying force has a longer-duration, which changes magnitude and direction with the phase of the wave as the wave passes under or across the structure. The varying force has vertical and horizontal forces. This force duration lasts typically between 3 to 15 seconds. The impact or slamming force has a very short duration, less than 0.1 to 0.001 seconds long. This force is generated when the wave crest begins to hit the deck. Impact wave force is directed in the horizontal direction of wave propagation and in the upward vertical direction. [18]

There are several methods to estimate wave-induced loads on bridges. The FHWA Hydraulic Engineering Circular No. 25 summarized a couple of these methods and presents the equations and methodology to determine the bridge deck elevation, which includes the following designs: nominal maximum wave height, depth limited maximum wave height approach, and the estimation of the maximum wave crest elevation. Wave load mitigation is an important concept that needs to be included in the design of new bridges and in the vulnerability analysis of existing bridges in order to avoid bridge failures caused by wave forces during a storm surge event [18][21]. One of the most common design methods to avoid wave forces in the superstructure is to elevate the bridge deck so that the storm wave crests pass under the low-chord of the bridge [18]

2.3.4.1 Example Impacts of Wave Forces on Bridges

Several bridges along the north central United States Gulf coast were damaged by Hurricane Ivan in 2004 and Hurricane Katrina in 2005 [18]. For example, the I-10 Escambia Bridge was damaged by the storm surge of Hurricane Ivan (See Figure 2.7). At the peak of the storm surge, the wave induced loads were large enough to move the decks off the bridge [18]. Figure 2.7 shows the spans moved by the storm (right side of the photo).

Figure 2.7: the I-10 Escambia Bridge damaged by Hurricane Ivan (Image form: FHWA [18])

Also, the US Highway 90 Bridge at the Biloxi Bay was damaged by Hurricane Katrina. The combination of storm surge and the intense waves inundated the bridge superstructure and separated the decks from the bridge [21] (See Figure 2.8).

Figure 2.8: US Highway 90 Bridge across Biloxi Bay (Image form: FHWA [21])

2.4 Bridges Damaged by Hurricane Katrina

The ASCE Technical Council on Lifeline Earthquake Engineering (TCLEE) along with the U.S DOT reported a total of 44 highway bridges damaged along the Gulf Coast region during Hurricane Katrina (Padgett, DesRoches et al. 2008) [22]. Four bridges were damaged in Alabama, seven in Mississippi including US-90 that required a complete replacement, and thirty three in Louisiana.

Table 2.1 shows the list of the 44 bridges damaged in Alabama, Louisiana, and Mississippi during Hurricane Katrina, including the type of bridge, damage state, and estimated repair or replacement cost [22]

Bridge name	Carried	Bridge type	Damage Sate	Damage source	Cost estimate		Surge elevation (m)
Alabama							
Bayou La Batre	Hwy. 188	fixed	Moderate	SC	$10,000		—
Dauphin Island Parkway	193	fixed	Moderate	I,SC	$6	million	—
Cochrane Africatown USA	US-90	Fix.	Extensive	I	$1	million	—
Mobile Delta Causeway	I-10	Fix.	Extensive	D	$1.14	million	—
Louisiana							
Bayou Des Allemands	LA-631	movable	Slight	wind	$3,000		0.98
Bayou Dulac	LA-57	movable	Slight	wind	$1,000		1.16
Country Club	LA-3127	movable	Slight	wind	$1,000		0.91
Galliano	LA-308	movable	Slight	wind	$5,000		1.95
Golden Meadow	LA-308	movable	Slight	wind	$9,000		1.95
Harvey Canal	LA-18	movable	Slight	wind	$2,000		3.54
Houma Navigation Canal	LA-661	movable	Slight	wind	$1,000		0.91
Houma Navigation Canal	LA-1	movable	Slight	wind	$2,000		0.91
Presque Isle @ Bayou Petite Caillou	LA-24	movable	Slight	wind	$1,000		—
Belle Chase	LA-23	movable	Moderate	wind	$200,000		4.08
Claiborne	LA-39	movable	Moderate	wind	$40,000		—
Intracoastal Waterway @ Larose	LA-1	movable	Moderate	wind	$170,000		1.34
Perez	LA-23	movable	Moderate	wind	$200,000		—
Seabrook	Local Road	movable	Moderate	wind	$25,000		3.11
St. Bernard Canal	LA-46	movable	Moderate	wind	$40,000		—
West Pearl River	US-90	movable	Moderate	EM,SC,W	$350,000		4.6
Bayou Barataria	LA-302	movable	Extensive	EM	$50,000		1.16
Bayou Lafourche @ Leeville	LA-1	movable	Extensive	SC, W	$1.60	million	2.13
Bayou Liberty	LA-433	movable	Extensive	EM,W	$1.50	million	3.47
Bonfouca	LA-433	movable	Extensive	EM,W	$200,000		3.57
Caminada Bay	LA-1	fixed	Extensive	D, SC	$500,000		2.44
Chef Menteur	US-90	movable	Extensive	EM, SC	$3.60	million	3.96
Doullut Canal	LA-11	movable	Extensive	EM, W	$700,000		3.44
East Pearl River	US-90	movable	Extensive	EM,SC,W	$400,000		4.6
Inner Harbor Navigation Canal	Florida Ave.	movable	Extensive	EM,I,W	$500,000		1.01
North Draw—Lake Pontchartrain	US-11	movable	Extensive	EM	$50,000		4.02
Rigolets Pass	US-90	movable	Extensive	EM,SC,W	$2	million	4.6
Rigolets Pass–Under Construction	US-90	movable	Extensive	I,W	$1.70	million	4.6
Tchefuncte River Madisonville	LA-22	movable	Extensive	EM,SC,W	$25,000		2.32
US 11 @ Lake Pontchartrain	US-11	movable	Extensive	EM,SC,W	$6	million	4.02
Yscloskey	LA-46	movable	Extensive	EM,SC,W	$900,000		5.12
Lake Pontchartrain	I-10	fixed	Complete	D, SC	$30	million	4.02
Pontchartrain Causeway	LA-Causeway	fixed	Complete	D, SC	$1.50	million	2.77
Mississippi							
David V. LaRosa	W. Wittman Rd	fixed	Moderate	D	$60,000		7.5
Biloxi Back Bay	I-110	movable	Extensive	I	$2.50	million	6.22
I-10 Pascagoula River	I-10	fixed	Extensive	D,I	$5.80	million	4.57
Popps Ferry	Popps Ferry Rd.	movable	Extensive	D,EM	$7.70	million	5.82
Biloxi-Ocean Springs	US-90	movable	Complete	D,EM	$275	million	6.58
US-90 Bay St. Louis	US-90	movable	Complete	D,EM	$276	million	5.58
US-90 Henderson Point	US-90	fixed	Complete	D	$1.90	million	7.01

D:deck movement EM: electrical/mechanical
I:impact SC:scour

Table 2.1. Bridges Damaged by Hurricane Katrina. (Image from Padgett et al, 2008 [22])

Padgett, et al provide the following description for each kind of damage state used to classify the bridges damaged during Hurricane Katrina [22].

- Slight: “Minor cracking and spalling to the abutment, cracks in shear keys at abutments, minor spalling and cracks at hinges, minor spalling at the column (damage requires no more than cosmetic repair), minor cracking to the deck, or slight damage to operator house.”
- Moderate: “Any column experiencing moderate (shear cracks) cracking and spalling (column structurally still sound) ,moderate movement of the abutment (<2 in), extensive cracking and spalling of shear keys, any connection having cracked shear keys or bent bolts, keeper bar failure without unseating, rocker bearing failure, moderate settlement of the approach, moderate scour of the abutment or approach, damage to guardrails, wind and/or water damage to operator house resulting in switchboard or content damage.”
- Extensive: “Any column degrading without collapse (shear failure) column structurally unsafe, significant residual movement at connections, or major settlement approach, vertical offset of the abutment, differential settlement at connections, shear key failure at abutments, extensive scour of abutments, or submerged electrical or mechanical equipment.”
- Complete: “Any column collapsing or connection losing all bearing support, which may lead to imminent deck collapse, tilting of substructure due to foundation failure.”

Figure 2.9 to 2.11 summarize the bridge damage state, bridge damage source, and bridge deck damaged and storm surge elevation. Figure 2.9 shows the total number of bridges by damage state.

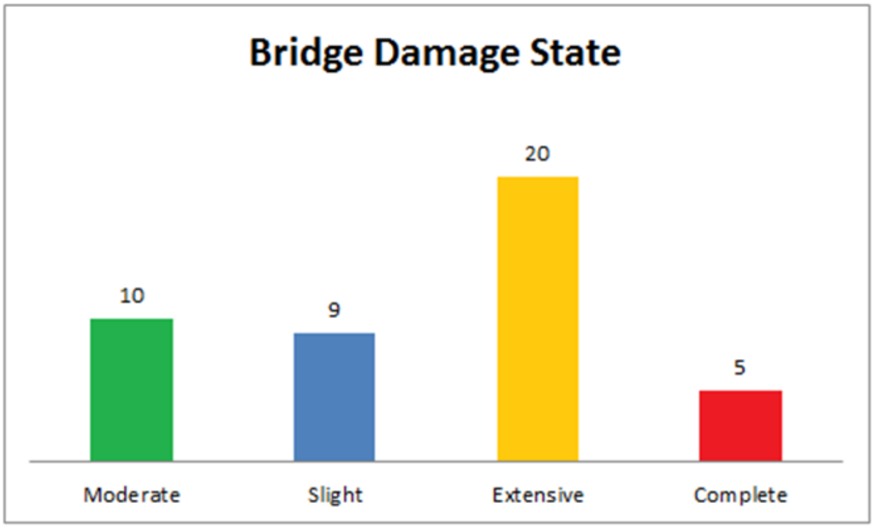


Figure 2.9: Bridge Damage State

The majority of the bridges presented an extensive damage state after the storm surge event. A total of 10 bridges had a moderate damage state. Nine bridges presented slight damage and five bridges presented complete damage. [Two from Louisiana: Lake Pontchartrain and Pontchartrain Causeway (Surge elevations: 4.02 m; 2.77 m) and three from Mississippi: Biloxi-Ocean Springs, US-90 Bay St. Louis, US-90 Henderson Point (surge elevations: 6.58 m; 5.58 m; 7,01 m)].

Figure 2.10 shows the bridge damage by source. Notice that the total number of bridges is not equal to 44 because as can be observed in Table 2.1, several bridges present more than one damage source.

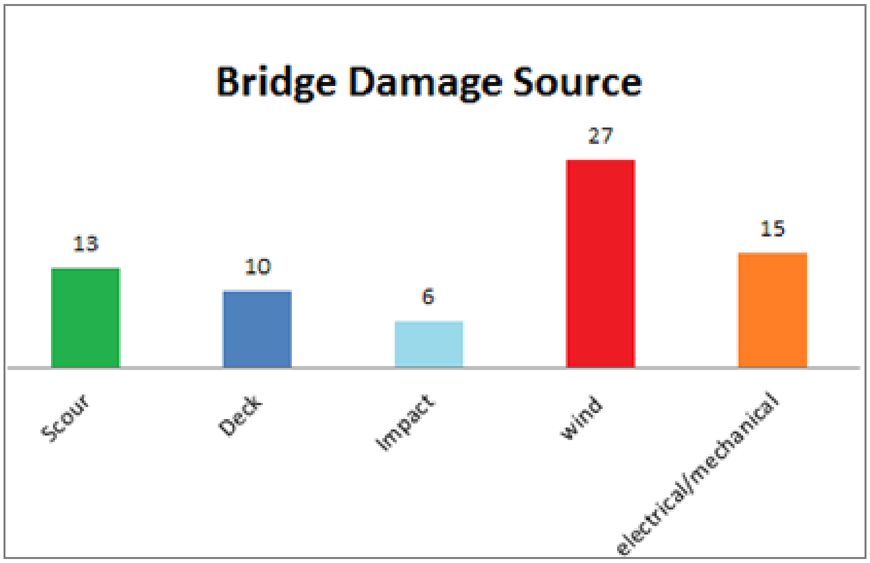


Figure 2.10 Bridge Damaged Source

Even though wind and electrical /mechanical damage sources were the ones that affected most of the 44 bridges scour and deck damage were also very significant damage sources on bridges during Hurricane Katrina.

Figure 2.11 shows 9 of the 10 bridges that presented deck damage and the surge elevation for each bridge. The colors show the damaged state where yellow is extensive, red is complete, and green is moderate damage.

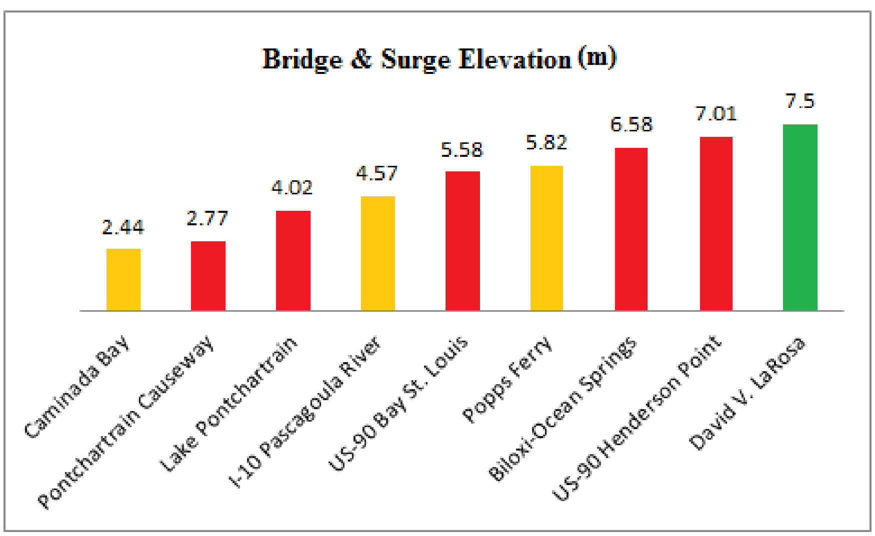


Figure 2.11 Bridge & Surge Elevation

Storm surge elevation is a critical factor of damage for bridges during a storm surge. From figure 2.11 it can be observed that many of the bridges that presented extensive damage and all the bridges that presented complete damage were exposed to a high surge elevation during Hurricane Katrina.

2.5 Summary

As a summary of this chapter, it can be stated that a hurricane event can produce significant impacts on the transportation systems in the coastal areas. The storm surge is the most destructive aspect of a hurricane. However, there are other aspects that cause significant damages in the transportation systems such as the violent winds, high waves, and the torrential rain. Global warming and rising sea levels increase the possibility of having more severe hurricane events and consequently, the flooding event. Storm surge can cause partial or complete damage of roads and railroads subjected to it. Also, storm surge can cause the formation of scour on the piers and abutments of coastal bridges. Depending on the magnitude of the storm surge, complete or partial damage on coastal bridges can be produced by general and local scour at its abutments or piers. Also, wave forces can produce large damages on coastal bridges during a hurricane event. The intense waves can inundate the bridge superstructure and separate the decks from the bridges. The examples (provided in this chapter) of railroads, roads, and bridges damaged by the storm surge of different hurricane events in the United States illustrates the relevance of this study by showing possible outcomes of a major storm.

CHAPTER 3

METHODOLOGY AND DATA SOURCES

In order to identify the transportation assets on the Georgia coast that would likely be inundated by a storm surge produced by a hurricane event, it is necessary to have the storm surge elevation and the different transportation assets' elevation information. The storm surge elevation is obtained from the SLOHS (Sea, Lake, and Overland Surge from Hurricanes) model. GIS (Geographic Information Systems) data was used for the elevation of the transportation systems. After obtaining this information, the storm surge elevation of the selected types of hurricanes was compared to the elevation of the selected roads, interstates, railroads, and airports in coastal Georgia. This information then helped identify those assets affected by the storm surge. This analysis was performed with ArcGIS software. This section describes the software used in the analysis, the data and sources used, and the GIS analysis.

3.1 Storm Surge Model

SLOSH (Sea, Lake and Overland Surges from Hurricanes)

SLOSH is a computer model used to estimate storm surge heights and winds produced by historical, hypothetical, or predicted hurricanes. The model was developed by the National Weather Service and is run by the National Hurricane Center (NHC). SLOSH is commonly used for hurricane evacuation plans and hurricane evacuation studies. This model is used by agencies such as The Federal Emergency Management Agency (FEMA), the National Oceanographic and Atmospheric Administration (NOAA), and U.S. Army Corps of Engineers (USACE) [25]. SLOSH can estimate the potential flooding from storm surge (the height of the storm surge) caused by a hurricane event for a specific coastal region “SLOSH basin”. However, it does not include rainfall amounts, river flow, or wind-drive waves and it does not predict the specific areas that will be inundated during a hurricane event. The accuracy of the model is within ±20% of the peak storm surge [25]. The SLOSH model accounts for astronomical tides. The calculations are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, and other physical features.

3.1.1 Model inputs and Outputs

Model Inputs:

- Hurricane Track
  - Pressure
  - Location
  - Direction
  - Radius of max winds
  - Forward speed
- Topography
- Bathymetry

Model output:

- Storm surge heights.

- Surface envelope of the highest surges for each cell in the grid.
- Time histories of surges at selected grid points.

The SLOSH output can be applied to estimate storm surge and flooding for a given hurricane category, forward speed, and direction. SLOSH can identify risky areas that would need an evacuation. The storm elevation of each grid "output" cell is the average of the ground or water surface elevation found in that grid cell [25]. Storm surge elevation outputs can be opened in other programs such as ArcGIS to then calculate areas of inundation.

SLOSH has three types of storm files to choose from: a MEOW, Historical Storm, and a MOM. The MEOW "Maximum Envelope of Water" is the maximum elevation that the storm surge reaches at each grid location for a given hypothetical storm in the SLOSH Basin [25]. The hypothetical storm is defined by 4 components: category (1 to 5), forward speed, direction of motion, and tide level. The MEOW is use for the worst-case scenario.

The following are the parameters and data selected for the transportation system inundation analysis of the Georgia Coast. The basin selected for the Georgia coast analysis is the Savannah/Hilton Head v3 basin. The MEOW data files were used for the estimate of the hurricanes' storm surge elevations. All hurricanes analyzed in this thesis were selected with high tide because it generates a "worst case" estimate. Surge heights for storms with a North East direction (going away from the coast) are either near to zero or zero and the storms do not produce a large inland surge; therefore this direction was not selected for the analysis. Storms with directions North-North East, and North were not selected for the analysis because the surge that those storms generate is much lower than North West (NW), North-North West (NNW), West North-West (WNW), and West (W). Storms with the direction NW, WNW, and W generate very similar surge heights, with a difference of less than 50 cm (1.64 feet). Storms with direction NNW generate lower surge; about 1 m (3.28 feet) lower, compared to the NW, WNW, and W directions.

A group of 12 hypothetical hurricanes was selected for this analysis. The selection of this group was based on a worst case scenario, that is, the storms with the highest storm surge generated, where generally the storm surge elevations are approximately higher than 4 meters (13.23 feet).

- Group: Direction: West North-West; Category: 3, 4, and 5; Forward Speed: 5 mph, 15 mph, 25 mph, and 35 mph; High tide.

Even though category 1 and 2 produced low storm surges, they were selected for the analysis to provide a basis of comparison of the effect of more serious storms. The hypothetical storms (WNW) are analyzed with a speed of 35mph and high tide. For these two categories, only maps are generate, lengths under or above surge will be not provided. The directions North West, North-North West, and West were not selected because of their similarity with the group of storms already selected.

3.1.2 Example of MEOW hypothetical Storm for the Savannah/Hilton Head v3 basin (Georgia Coast)

The SLOSH Display Output shows the storm surge elevation in meters for each cell of the storm grid. It also shows the trajectory of the storm. Figure 3.1 shows the outputs of four hypothetical hurricanes using W, NW, WNW, and NNW directions.

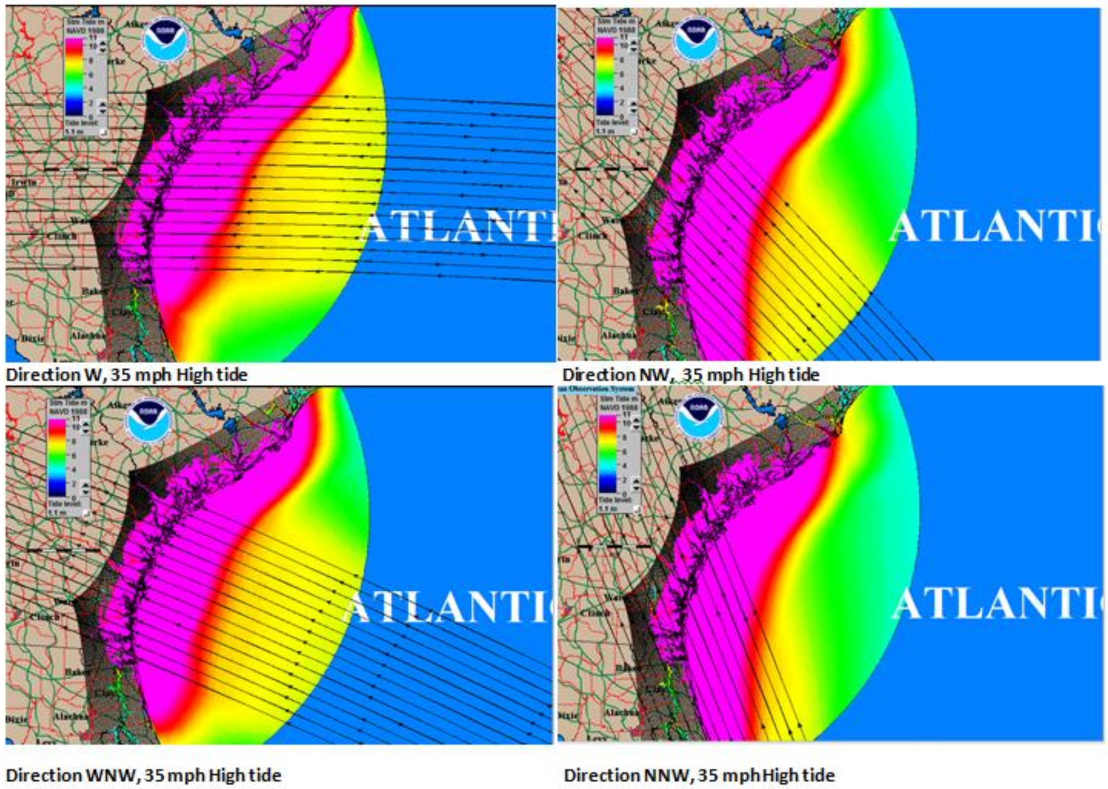


Figure 3.1: SLOSH Display output. (MEOW hypothetical storm Savannah/Hilton Head v3 basin: Direction: W, NW, WNW, and NNW; Category 5; Speed: 35 mph; High tide)

3.2 GIS Software and Data

A geographic Information System (GIS) is a system that integrates hardware, software, and data and is designed to capture, store, manipulate, analyze, manage, and display all types of geographically referenced information [26]. The GIS software used for the transportation systems inundation analysis of the Georgia coastal area was ArcGIS9.3.

The elevation data of the Georgia coast was obtained from the National Elevation Dataset (NED) of the U.S Geological survey (USGS) [25]. The NED raster elevation data was selected with a resolution of 1/3 arc-second (about 10 meters). The counties, state, highways, state roads, railroads, airports, and ports data (coverages, shapefiles, or geodatabses) was obtained from the Georgia GIS Clearinghouse [24]. Because the airports and ports GIS data only illustrate a single point for its location, a polygon was created to represent all the area. The polygons were created with latitude and longitude coordinates of the airports and ports obtained from Google Earth. Even though these polygons do not reflect the exact shape area of the airports and ports, these approximate areas facilitated the inundation analysis of these facilities. To have a more conservative analysis, the polygon areas were created slightly greater than the actual area.

3.2.1 Definitions: GIS Raster and Vector models

ArcGis Help Center (2011) defines raster as a "matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information" [28]. Raster cells can only store one numeric value of information such as elevation and temperature. Vector model refers to the geographic features that are located/stored using x-y coordinate pairs in a plane coordinate system [28]. These features are represented by points, lines, or polygons. These features can be stored in coverage, shape files, or goedatabases. Vector models include the geometry of the feature and an attribute table where many attributes (information) can be stored.

3.3 Methodology

State roads, highways, railroads, ports, and the principal airports of the Georgia coastal area were selected for the analysis. Google Earth, Georgia Ports Authority, GIS, and GDOT maps and information were used to select these transportation infrastructures. A description and maps of these transportation infrastructures were made to start the analysis. After the selection of the transportation facilities, the next step was to obtain the GIS data. All the GIS data obtained for this analysis was defined in the Geographic Coordinate System (Degrees of latitude and longitude). To obtain more accurate results in the mathematical operations and features geometry calculation, the Projected Coordinate System (planar coordinates) should be used for each vector and raster file used in the analysis [29]. Therefore, all the data was projected to a NAD 1927 UTM Zone 17 N. UTM is a projection for large scale maps that minimizes or eliminates distortion. UTM divides the globe into 60 zones at 6 degrees width where zone 17 corresponds with the Georgia coastal area [29]. Because the NED raster elevation data of the Georgia coast is expressed in meters, meter units were choosen for the projected coordinate system (NAD 1927- meters).

From the SOLSH software, the storm surge grid can be exported as a shape file. The units for the surge elevation are feet. Because the raster elevation data is in meters, the units of the storm surge shape files are changed to meters. Changing the units in the raster elevation file is a very complex procedure and may lead to significant errors. After the units of the storm surge are changed, the file is converted to a raster file. The cells' value in the new raster file corresponds to the storm surge elevation (m) value of the storm shapefile grid cells. Highways, roads, and railroads are represented as line features and airports and ports are represented as polygon features. This vector data does not have elevation information in the attribute table. Therefore, all the line and polygon features have to be converted to a raster file in order to obtain the elevation information of these features. When the transportation features are converted to a raster file, a value of zero is assigned to each of the grid cells. The same cell size of the elevation data was applied to the new raster files. A mathematical raster operation was performed to transfer the NED elevation data corresponding to each transportation raster file (interstates, roads, railroads, airports, and ports). In other words, the elevation raster file and the transportation raster file (at separate times) were added to get the elevation that corresponds to each cell. See figure 3.2

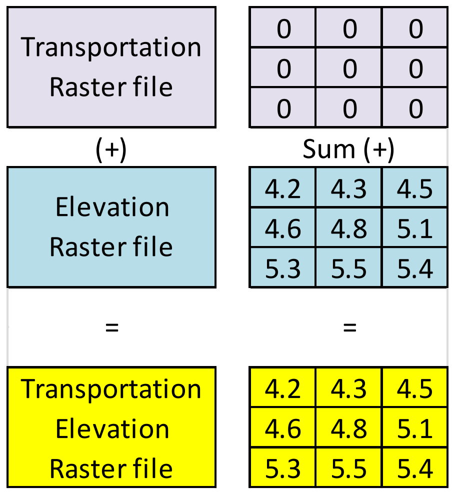


Figure 3.2: Raster Addition Operation

After determining the elevation in the transportation systems files, a similar operation is done to obtain the sections of the roads, interstates, railroads, airports, and ports under and above surge. The raster math equation is: Transportation elevation raster file minus (-) the storm surge elevation raster file equals (=) transportation above and under surge. See figure 3.3.

Transportation Elevation Raster file	4.2	4.3	4.5
	4.6	4.8	5.2
	5.3	5.5	5.4
(-)	minus (-)		
Storm Surge Elevation Raster file	7.3	7.2	0
	7.3	7.2	0
	7	7	7
=	=		
Transportation Features Under and Above Surge	-3.1	-2.9	4.5
	-2.7	-2.4	5.2
	-1.7	-1.5	-1.6

Figure 3.3: Raster Subtraction Operation

The positive values are the sections above surge and the negative values are the sections under the surge. Values from 0 to 1m (0 to 3.28ft) are considered to be "under surge" sections because at these levels the surge can be damaging to transportation infrastructures such as road shoulders, embankments, and rail ballasts. At this elevation, the infrastructure remains exposed to surge and wave forces equivalent to those that are under water. After determining the values of the transportation features under and above surge, the raster file is converted to a polygon shapefile. However, the polyline does not take negative values or zero. It will only generate a polyline for the positive values greater than one: Polygon shapefile is then intersected with the original polyline shape file of the transportation features (roads, interstate, and railroad) to obtain the values of features under and above surge. Finally, the length of all new segments formed in the roads, interstate, and railroad features are recalculated to obtain the length under and above surge.

GIS maps are created to show the transportation infrastructure under and above surge for each type of storm. Red represents a section under water and green represents a section above water. The storm surge color code grid is also shown in the map. Summary tables are provided to illustrate the length of state roads, highways, and railroads that are in risk during a specific storm. Also, a table for airports and ports is provided.

CHAPTER 4

TRANSPORTATION SYSTEM IN THE GEORGIA COASTAL AREA

The transportation networks analyzed are railroads, state roads, interstates, principal airports, and ports of the Georgia coast. The state roads, interstates, and railroads analyzed are located in the following counties: Chatham, Bryan, Liberty, Mcintosh, Glynn, Camden, Long, Wayne, and Brantley County. The Savannah International Airport, Hunter Army Air Field Airport, Glynco Jetport, Savannah Port, and Brunswick Port are also analyzed. Figure 4.1 shows the Georgia coast transportation system chosen for the analysis. (Also see appendix B-1 and B-2)

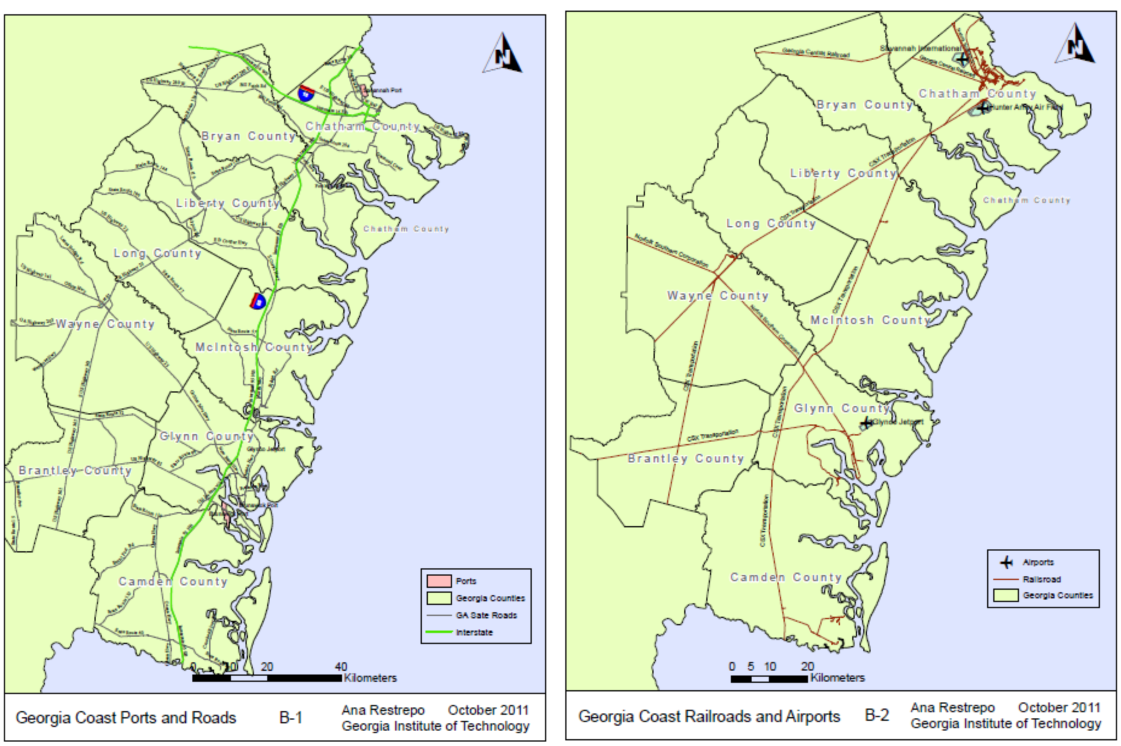


Figure 4.1: Georgia Coast - Railroad, Roads, Ports, and Airports Maps

4.1 State Roads, Railroads, and Interstate Roads

Approximately 928 kilometers (577 miles) of railroad and 1849 kilometers (1149 miles) of roads along the Georgia coast were selected for this study. The 1849 kilometers of roads include state roads and interstates passing through the 9 counties along the Georgia coast. The selection of the counties was based on the storm surge grid size/extent. In other words, every county where the storm surge could reach was selected.

Table 4.1: Miles of Railroad and roads selected for the study

County	County Code	Roads + Interstate Length		Rail Length	
		(Km)	(miles)	(Km)	(miles)
Brantley	25	154.21	95.82	76.37	47.45
Bryan	29	220.80	137.20	61.89	38.46
Camden	39	247.38	153.71	88.05	54.71
Chatham	51	331.88	206.22	289.69	180.00
Glynn	127	228.10	141.74	141.37	87.84
Liberty	179	226.78	140.92	68.37	42.48
Long	183	98.76	61.37	21.61	13.43
Mcintosh	191	169.33	105.22	31.07	19.31
Wayne	305	171.94	106.84	149.88	93.13
	Total	1849.19	1149.04	928.29	576.81

Table 2 illustrates the number of kilometer-miles for each section of the interstate crossing the Georgia coastal area selected for the study (9 counties). There are about 236 kilometers (147 miles) of interstate road exposed to storm surge.

Table 4.2: Number of Interstate miles Selected for Study

Interstate Name:	Length (Km)	Length (miles)
16	45.60	28.33
516	10.78	6.70
95	179.98	111.83
Total	236.36	146.86

4.2 Airports

4.2.1 Savannah International Airport

The Savannah/Hilton Head International Airport is located near the border of Georgia and South Carolina. For this study, about 10.12 square kilometers (2500 acres) of land are analyzed. The land acreage includes all the runway and taxiway systems, terminal buildings, and other buildings. Figure 4.2 shows the areas analyzed of the Savannah International Airport.

Figure 4.2: Savannah Airport (Image from Google Earth)

4.2.2 Hunter Army Air Field

Hunter Army Airfield is a military airfield located in Savannah, Georgia. About 11.4 square kilometers (~2800 acres) of land are analyzed. This area includes the runway, aircraft parking, buildings, and other facilities of the Hunter Army Airfield. Figure 4.3 Shows the area analyzed.

Figure 4.3: Hunter Army Airfield (Image from Google Earth)

4.2.3 Brunswick Glynco Jetport (Brunswick Golden Isles Airport)

Glynco Jetport is located in the city of Brunswick in Glynn County, Georgia. About 4.45 square kilometers (1100 acres) of land are analyzed. This area includes the runway, aircraft parking, buildings, and other facilities of the Hunter Army Airfield. Figure 4.4 Shows the area analyzed.

Figure 4.4: Glynco Jetport (Image from Google Earth)

4.3 Ports

4.3.1 Savannah Port

The Savannah port is located in Chatham County, Georgia and is composed of the Garden City Terminal and the Ocean Terminal. Garden City Terminal has 4.856 square kilometers (1200 acres) of area and the Ocean Terminal has 0.811 square kilometers (200.4 acres) of area [30]. Approximately the same area of terminal ports was analyzed. (See Figure 4.5)

Figure 4.5: Savannah port, Garden City Terminal (right) and Ocean Terminal (left) (Image from Google Earth)

4.3.2 Brunswick Port

The Brunswick Port is located in the Glynn Country, Georgia. The port is composed of 4 terminals: Colonel’s Island Terminal (6.88sq km or 1700 acres), Mayor’s Point Terminal (0.089sq km or 22 acres), East River Terminal (0.166sq km or 41 acres or), and the Lanier Docks Terminal (0.10sq km or 25 acres) [30]. Approximately the same area of terminal ports was analyzed. (See figure 4.6)

Figure 4.6: The Brunswick Port, Colonel’s Island Terminal (left), and East River, the Lanier Docks Terminal (right), Mayor’s Point (top right) (Image from Google Earth)

CHAPTER 5

GIS ANALYSIS RESULTS

This section contains maps and summary tables of the results obtained for each of 12 hypothetical storms. All maps illustrate a color code of transportation features and a color code of storm surge elevations. There are three maps per hypothetical storm: the first map is for the roads, the second map is for the interstate roads, airports, and ports, and the last map is for the railroads. Appendix B provides the full view of each of these maps (B-3 to B-44). In this section, only one of the three maps generated for each storm is shown completely, or has full view. The maps illustrate the roads under surge (red) and above surge (green). Note that for Brantley, Bryan, Liberty, Long, and Wayne Counties, only the sections of roads that the storm surge may reach are shown. The other sections of the roads will be not affected by the storms. There are three summary tables generated for each hypothetical storm. The tables provide information on lengths of roads, railroads, and interstate under surge. The tables also show maximum, minimum, and average levels of surge above the transportation feature (represented with a negative sign (-)) and from 0 to 1 meters under the transportation feature (positive values). The lengths of features under surge, and surge levels above and under (0 to 1m/3.3ft) the roads and railroads are summarized by county and interstate roads are summarized by name.

5.1 West North-West Category 3

5.1.1 Hypothetical Storm: WNW Category 3, Forward Speed 05 mph or 8 km/hr, and High Tide

(WNW305i4)

- State Roads

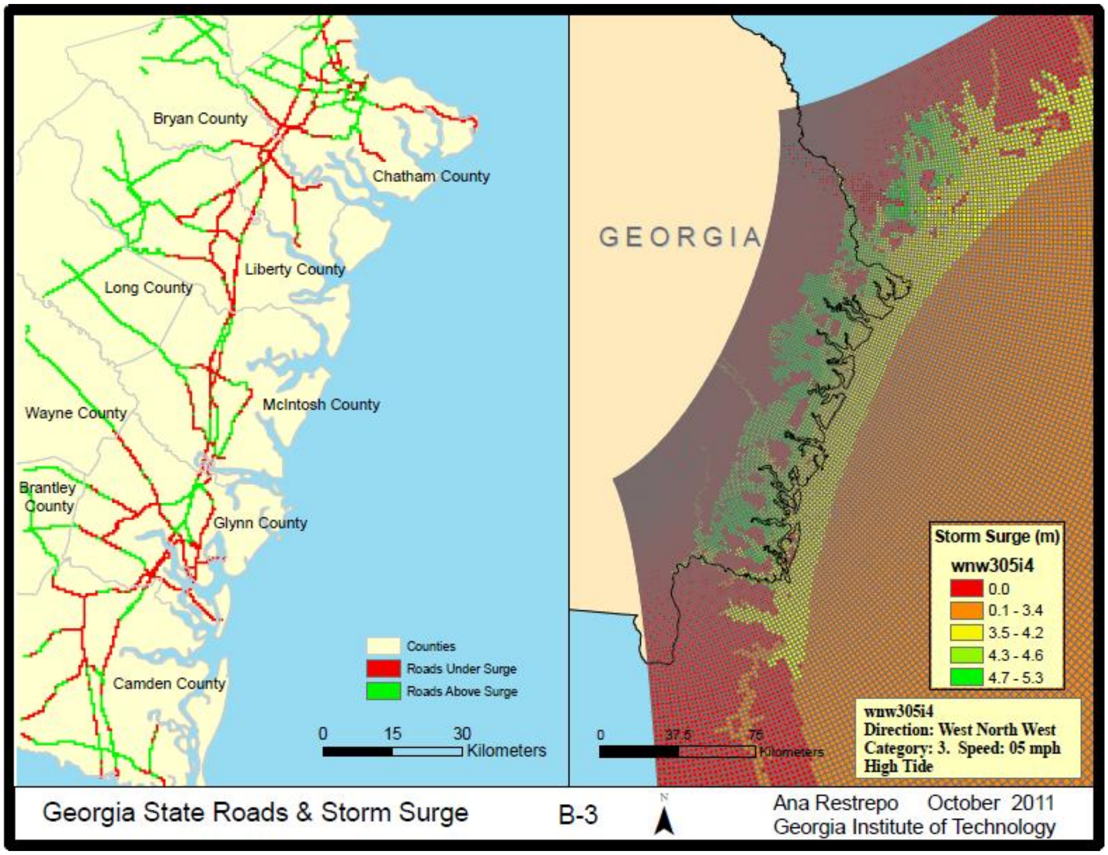


Figure 5.1: WNW305i4 Georgia State Roads & Storm Surge (see appendix B-3)

Table 5.1: Length of State Roads under Surge, WNW305i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 05 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	70.14	43.59	31.8%	-4.90	0.80	-1.45
	Camden	39	106.82	66.31	43.2%	-4.90	1.00	-1.27
	Chatham	51	142.85	88.76	43.0%	-4.80	0.98	-1.49
	Glynn	127	163.86	101.81	71.8%	-4.54	0.96	-1.50
	Liberty	179	84.80	52.69	37.4%	-4.50	0.97	-1.53
	Long	183	none	none	none	none	none	none
	McIntosh	191	79.41	53.19	46.9%	-4.47	0.98	-1.17
	Wayne	305	0.30	0.19	0.2%	-1.50	-0.50	-1.00
		Total	648.19	406.54		Average length of road segments: 200 m		

Roads in Brantley and Long Counties are not affected by this storm surge. Only a very small section of Wayne County roads are affected (0.30 km or 0.19 mi). Approximately 648 kilometers (406 miles) of road in Bryan, Camden, Chatham, Glynn, Liberty, and McIntosh counties are affected by this storm. For this storm the maximum level of surge above the roads is about 4.9 meters (16.07 ft) and the minimum level is 0.98 meters (3.2 ft) under the road elevation. Table 5.1 shows that in all segments of roads affected by the storm surge, the average surge levels are above the road. Glynn County roads have the highest percent of roads under surge: 71.8% of its roads are under surge elevation.

- Interstates, Airports, Ports, and Railroads

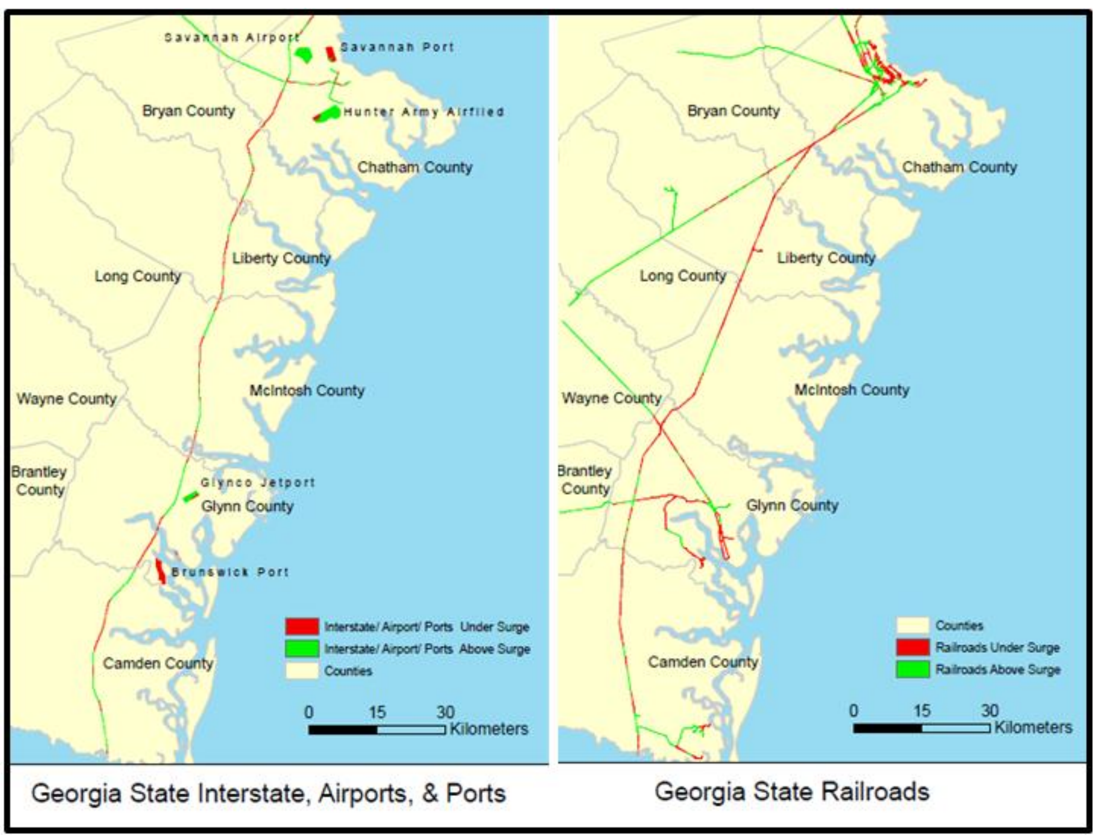


Figure 5.2: WNW305i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.2 shows that the areas assigned to the Savannah and Brunswick Ports are completely under surge elevation. The Savannah Airport is not affected by this storm, and a small section of the area assigned to the Hunter Army Airfield and Glynco Jetport is affected. Because these affected sections are in the laterals of the polygons, the terminals and runways of the airports are considered to be out of the affected area. See appendix B (B-4 & B-5) for a full view of the maps.

Table 5.2: Length of Interstate under Surge, WNW305i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 05 mph; High tide	16	7.22	4.49	12.6%	-2.90	0.92	-0.83
	516	1.23	0.77	11.4%	-0.41	0.93	0.03
	95	96.53	59.98	53.6%	-4.90	0.98	-1.88
	Total	104.98	65.23		Average length of road segments: 100 m		

Approximately 105 kilometers (65 miles) out of 248 kilometers (131 miles) of interstate roads analyzed are affected by this storm surge. The maximum level of water above the interstate road is about 4.46 meters (14.63 ft) and the minimum level is 1 meter (3.2 ft) under the interstate road elevation. Table 5.2 shows that for all segments of interstate roads affected by the storm surge, the average surge levels are above the road. Interstate 95 has the highest percent of road under surge, 53.6%.

Table 5.3: Length of Railroads under Surge, WNW305i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 05 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	20.16	12.52	32.6%	-4.07	0.99	-1.20
	Camden	39	48.35	30.05	54.9%	-4.90	0.78	-1.08
	Chatham	51	146.34	90.93	50.5%	-4.70	0.99	-1.88
	Glynn	127	105.11	65.31	74.4%	-4.50	0.90	-1.15
	Liberty	179	30.68	19.07	44.9%	-4.09	0.94	-1.51
	Long	183	none	none	none	none	none	none
	McIntosh	191	21.87	13.59	70.4%	-3.69	0.93	-1.05
	Wayne	305	0.36	0.22	0.2%	-0.50	-0.50	-0.50
		Total	372.87	231.69		Average length of railroad segments: 100 m		

Figure 5.2 (right) and Table 5.3 show that railroads in Brantley and Long County are not affected by this storm surge. Approximately 373 kilometers (232 miles) of railroads in the other seven counties are affected. The maximum level of surge above the railroads is about 4.9 meters (16.07 ft) found in Camden County. The minimum level is 0.99 meters (3.2 ft) under the road elevation. Table 5.3 shows that for all segments of the railroads affected by the storm surge, the average surge levels are above the railroads. Glynn and McIntosh County railroads have the highest percent of railroad under surge: 74.4% and 70.4%, respectively.

5.1.2 Hypothetical Storm: WNW Category 3, Forward Speed 15 mph or 24.14 km/hr, and High Tide

(WNW315i4)

- State Roads

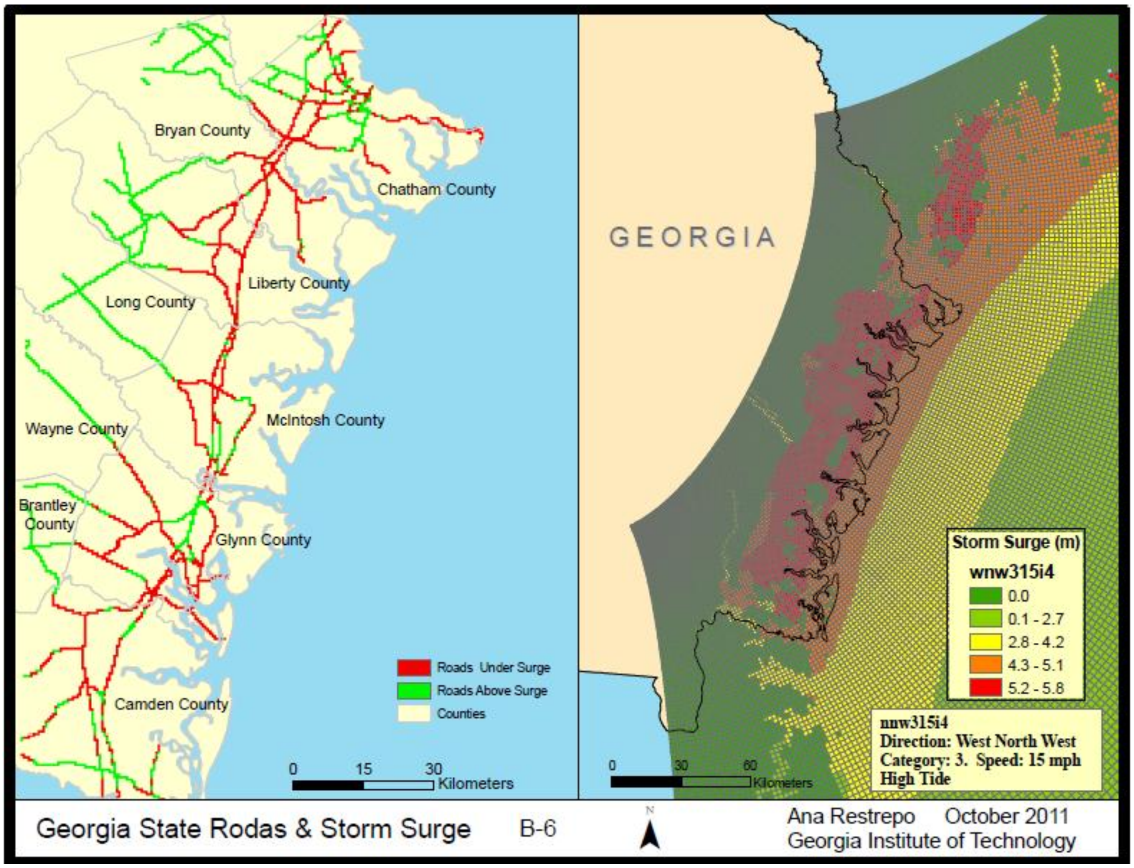


Figure 5.3: WNW315i4 Georgia State Roads & Storm Surge (see appendix B-6)

Table 5.4: Length of State Roads under Surge, WNW315i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 15 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	86.77	53.92	39.3%	-5.60	0.84	-1.94
	Camden	39	112.67	70.01	45.5%	-5.40	1.00	-1.48
	Chatham	51	186.47	115.87	56.2%	-5.60	1.00	-1.81
	Glynn	127	177.48	110.29	77.8%	-5.40	0.67	-2.19
	Liberty	179	105.91	65.81	46.7%	-5.50	0.89	-1.77
	Long	183	none	none	none	none	none	none
	McIntosh	191	123.21	76.56	72.8%	-5.31	0.97	-1.34
	Wayne	305	1.25	0.78	0.7%	-2.30	-0.30	-1.05
		Total	793.76	493.23		Average length of road segments: 200 m		

Roads in Brantley and Long Counties are not affected by this storm surge. Only a small section of Wayne County roads are affected (1.27 km or 0.78 mi). Approximately 794 kilometers (493 miles) of road in Bryan, Camden, Chatham, Glynn, Liberty, and McIntosh Counties are affected by this storm. The maximum level of surge above the roads is about 5.6 meters (18.37 ft) and the minimum level is 1 meter (3.2 ft) under the road elevation. Table 5.4 shows that in all the segments of the roads affected by the storm surge, the average surge levels are more than one meter above the road. Glynn and McIntosh County roads have the highest percent of road under surge: 77.8% and 72.8%, respectively.

- Interstates, Airports, Ports, and Railroads

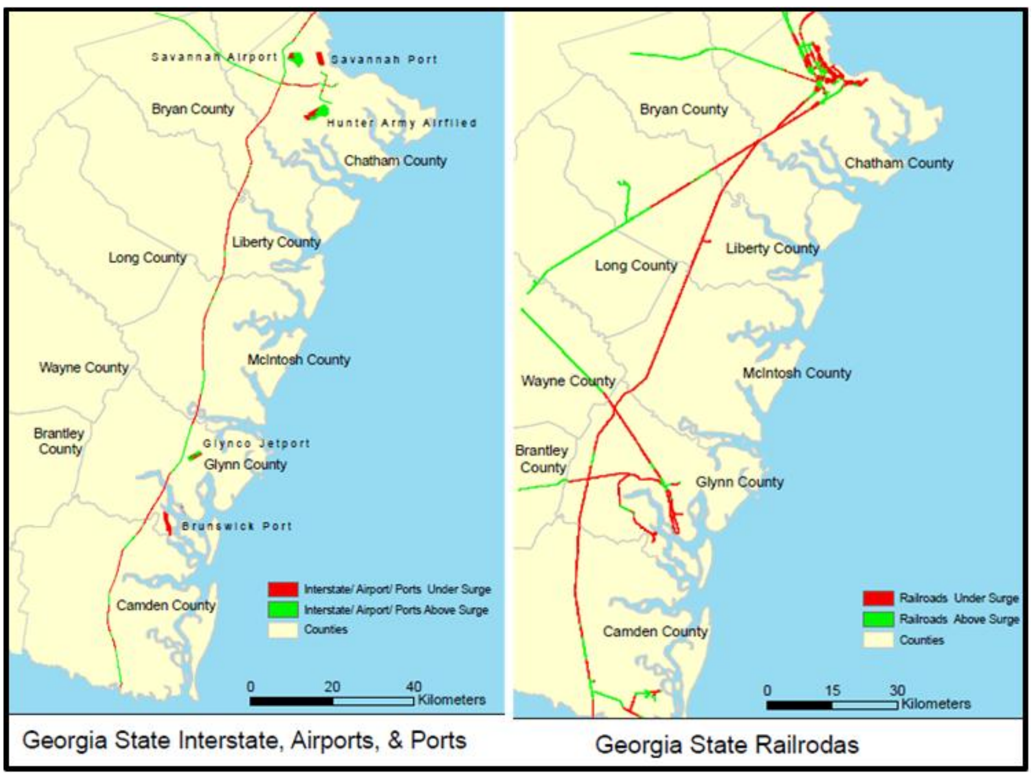


Figure 5.4: WNW315i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.4 shows that the areas assigned to the Savannah and Brunswick Ports are completely under the surge elevation. A small section of the area assigned to the Savannah Airport is affected by the storm. Because this affected section is in the laterals of the polygon, the terminals and runways of the airports are considered to be out of the affected area. However, the lower section of the runway, or the ends, may be affected. The Hunter Army Airfield and the Glynco Jetport are affected by this storm. Because the affected sections in these airports' polygons are near the center of the polygon, some sections of the runway or terminals of these airports (especially the Glynco Jetport) are considered to be affected by the storm. See appendix B (B-7 & B-8) for a full view of the maps.

Table 5.5: Length of Interstate under Surge, WNW315i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 15 mph; High tide	16	12.08	7.51	21.1%	-4.06	0.99	-1.21
	516	2.37	1.47	22.0%	-2.03	0.94	-0.24
	95	122.53	76.14	68.1%	-5.70	0.98	-2.11
	Total	136.98	85.12		Average length of road segments: 100 m		

Approximately 137 kilometers (85 miles) of interstate roads are affected by this storm surge. The maximum level of water above the interstate roads is about 5.7 meters (18.7 ft) and the minimum level is 0.99 meters (3.2 ft) under the road elevation. Table 5.5 shows that in all the segments of interstate roads affected by the storm surge, the average surge levels are above the road up to 2.11 meters – average elevation (6.9 ft). Interstate 95 has the higher percent of road under surge, 68.1%.

Table 5.6: Length of Railroads under Surge, WNW315i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 15 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	25.58	15.89	41.3%	-4.77	0.85	-1.68
	Camden	39	56.50	35.11	64.2%	-5.40	0.80	-1.38
	Chatham	51	180.24	111.99	62.2%	-5.45	0.97	-2.02
	Glynn	127	124.95	77.64	88.4%	-5.40	0.90	-1.80
	Liberty	179	38.83	24.13	56.8%	-4.75	0.82	-1.74
	Long	183	none	none	none	none	none	none
	McIntosh	191	30.96	19.23	99.6%	-4.39	0.45	-1.26
	Wayne	305	1.66	1.03	1.1%	-1.30	-0.30	-0.97
		Total	458.71	285.03		Average length of railroad segments: 100 m		

Table 5.6 shows that the railroads of Brantley and Long Counties are not affected by this storm surge. Approximately 459 kilometers (285 miles) of railroads in the other seven counties are affected by this storm. The maximum level of water above the railroad is about 5.45 meters (17.88 ft), found in Chatham County. The minimum level is 0.90 meters (2.85 ft) under the road elevation. Table 5.6 shows that for all the segments of interstates affected by the storm surge, the average surge levels are above the railroads. The average surge levels start at 0.97 meters (3.18 ft) and go up to 2.02 meters (6.62 ft) above the elevation of the railroads. Glynn and McIntosh County railroads have the highest percent of railroad under surge: 88.4% and 99.6%, respectively.

5.1.3 Hypothetical Storm: WNW Category 3, Forward Speed 25 mph or 40.23 km/hr, and High Tide

(WNW325i4)

- State Roads

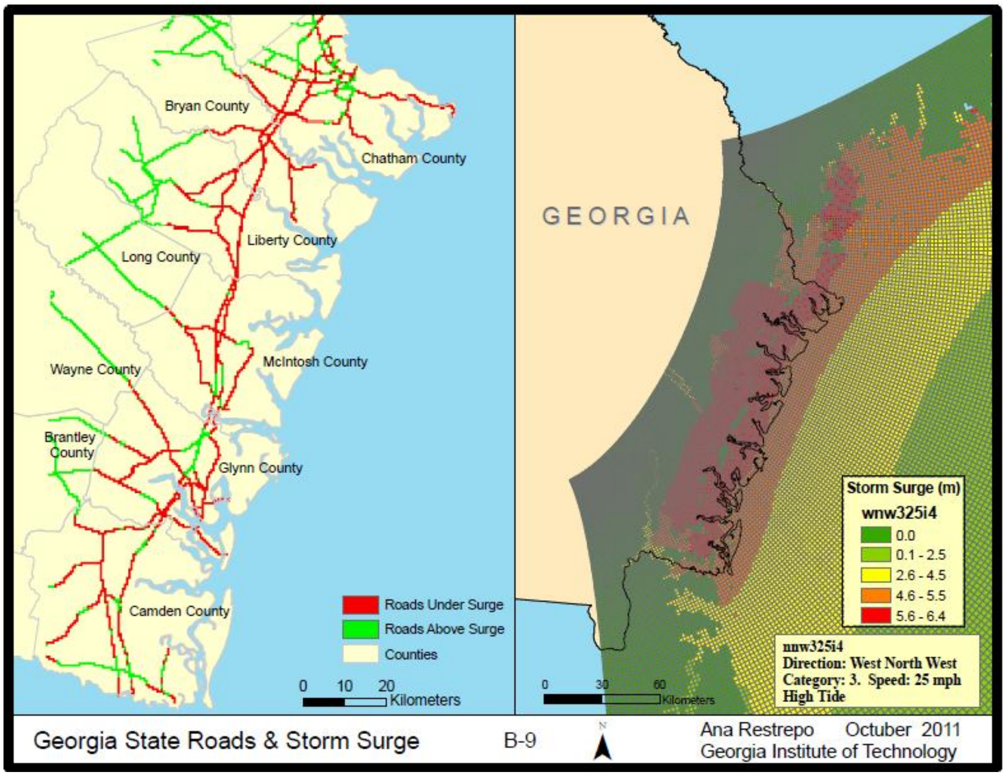


Figure 5.5: WNW325i4 Georgia State Roads & Storm Surge (see appendix B-9)

Table 5.7: Length of State Roads under Surge, WNW325i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 25 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	100.53	62.47	45.5%	-6.10	0.97	-1.98
	Camden	39	157.27	97.72	63.6%	-5.94	0.90	-1.72
	Chatham	51	206.15	128.10	62.1%	-6.10	0.90	-1.94
	Glynn	127	184.54	114.67	80.9%	-6.00	0.71	-2.81
	Liberty	179	111.50	69.28	49.2%	-6.10	0.82	-1.90
	Long	183	1.41	0.87	1.4%	0.01	0.01	0.01
	McIntosh	191	140.79	87.48	83.1%	-5.81	0.97	-1.64
	Wayne	305	1.25	0.78	0.7%	-2.90	-0.90	-1.65
		Total	903.45	561.38		Average length of road segments: 200 m		

Table 5.7 shows that the roads in Brantley County are not affected by this storm surge and that only a small length of the roads of Long and Wayne Counties are affected. Long County has 1.41kilometers (0.87 miles) of road under surge and Wayne County has 1.25 kilometers (0.78 mi) of road under the surge. Unlike Long County, Wayne County has all the road segments affected by this storm under the surge with a minimum surge elevation above the road of 0.90 meters (2.95 ft) and a maximum of 2.9 meters (9.51 ft). Approximately 904 km (561 mi) of road in Bryan, Camden, Chatham, Glynn, Liberty, Long, and McIntosh Counties are affected by this storm. The maximum level of water above the roads is about 6.10 meters (20.01 ft) and the minimum level is 0.97 meters (3.18 ft) under the road elevation. Table 5.7 shows that for all the segments of the roads affected by the storm surge, the average surge levels are above the road except for the roads segments of Long County, which have a constant surge level of 0.01 meters under the road segments. Glynn and McIntosh Counties roads have the highest percent of road under surge, 80.9% and 83.1%, respectively.

- Interstates, Airports, Ports, and Railroads

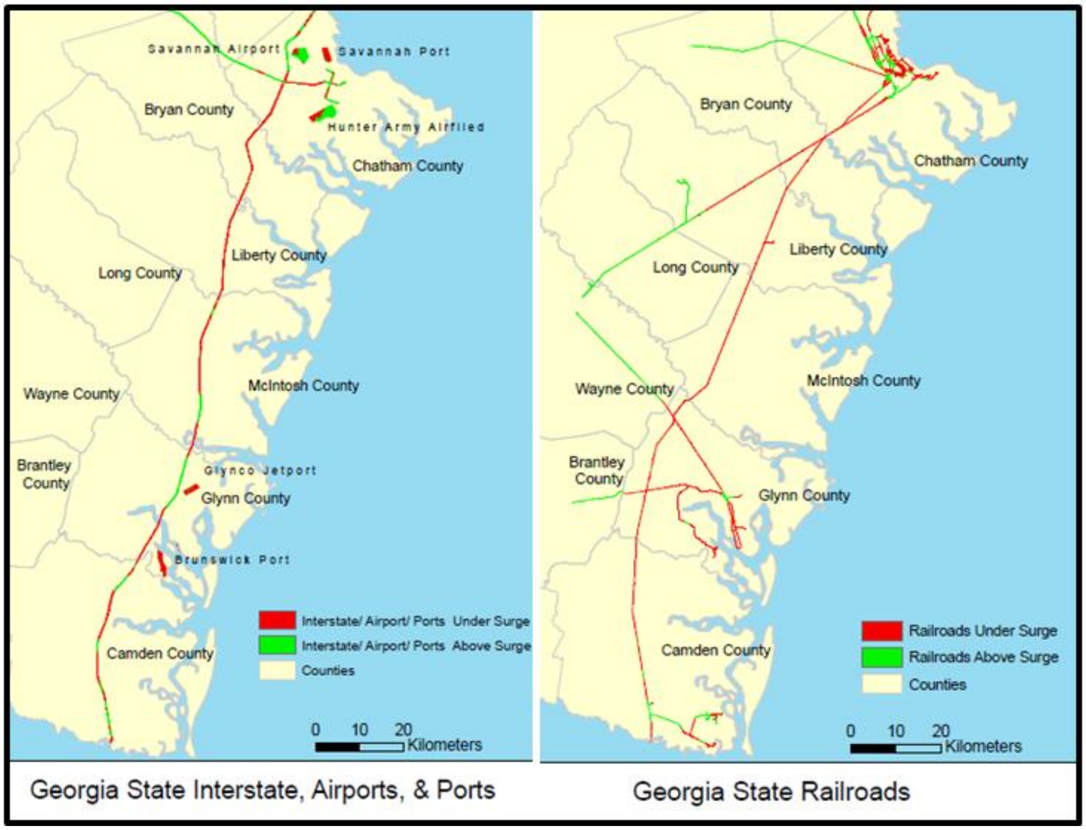


Figure 5.6: WNW325i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.6 shows that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. A small section of the area assigned for the Savannah Airport is affected by the storm. Because this section is in the laterals of the polygon, the terminals and runways of the airport are considered to be out of the affected area. However, access roads, the ends of the runways, and some buildings can be affected by the surge. Hunter Army Airfield is affected by the storm. Because the red section in the airports' polygon is near to the center of the polygon, some sections infrastructures or terminals are considered to be affected. Glynco Jetport ground elevation is completely under the surge, therefore terminals, and runways are subjected to the surge. See appendix B (B-10 & B-11) for a full view of the maps.

Table 5.8: Length of Interstate under Surge, WNW325i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 25 mph; High tide	16	12.94	8.04	22.6%	-4.36	0.92	-1.40
	516	3.59	2.23	33.3%	-2.03	0.65	-0.43
	95	129.60	80.53	72.0%	-6.20	1.00	-2.43
	Total	146.13	90.80		Average length of road segments: 100 m		

Approximately 146 kilometers (90.8 miles) of interstate roads are affected by this storm surge. The maximum level of water above the interstate is about 6.20 meters (20.34 ft), found on Interstate 95. The minimum level is 1 meter (3.28 ft) under the interstate road elevation. Table 5.8 shows that for all the segments of interstate roads affected by the storm surge, the average surge levels are above the road elevation. The average surge levels above the interstate roads varies from 0.43meters (1.41 ft) up to 2.43 meters (7.92 ft). Interstate 95 has the highest percent of road under surge, 72%.

Table 5.9: Length of Railroads under Surge, WNW325i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 25 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	25.67	15.95	41.5%	-5.17	0.74	-2.01
	Camden	39	60.24	37.43	68.4%	-5.80	0.92	-1.71
	Chatham	51	182.05	113.12	62.8%	-5.95	0.99	-2.23
	Glynn	127	131.37	81.63	92.9%	-6.00	0.48	-2.39
	Liberty	179	43.95	27.31	64.3%	-5.05	0.52	-1.84
	Long	183	none	none	none	none	none	none
	McIntosh	191	31.07	19.31	100.0%	-4.99	0.83	-1.69
	Wayne	305	1.66	1.03	1.1%	-1.90	-0.90	-1.57
		Total	476.03	295.79		Average length of railroad segments: 100 m		

Railroads in Brantley and Long County are not affected by this storm surge. A small section of Wayne County railroads are affected, only 1.66 kilometers. Approximately 476 kilometers (296 miles) of railroads in Bryan, Camden, Chatham, Glynn, Liberty, McIntosh, and Wayne Counties are affected by this storm. The maximum level of water above the railroads is about 6 meters (19.68 ft) and the minimum level is 0.99 meters (3.24 ft) under the railroad elevation. Table 5.9 shows that for all the segments of the railroads affected by the storm surge, the average surge levels are above the railroad track elevation. The average surge levels start on 1.57 meters and go up to 2.39 meters above the elevation of the railroads. Table 5.9 shows that 100% of the McIntosh County railroads are under surge. Glynn County has 92.2% of its railroads under the surge elevation.

5.1.4 Hypothetical Storm: WNW Category 3, Forward Speed 35 mph or 56.32 km/hr, and High Tide.

(WNW335i4)

- State Roads

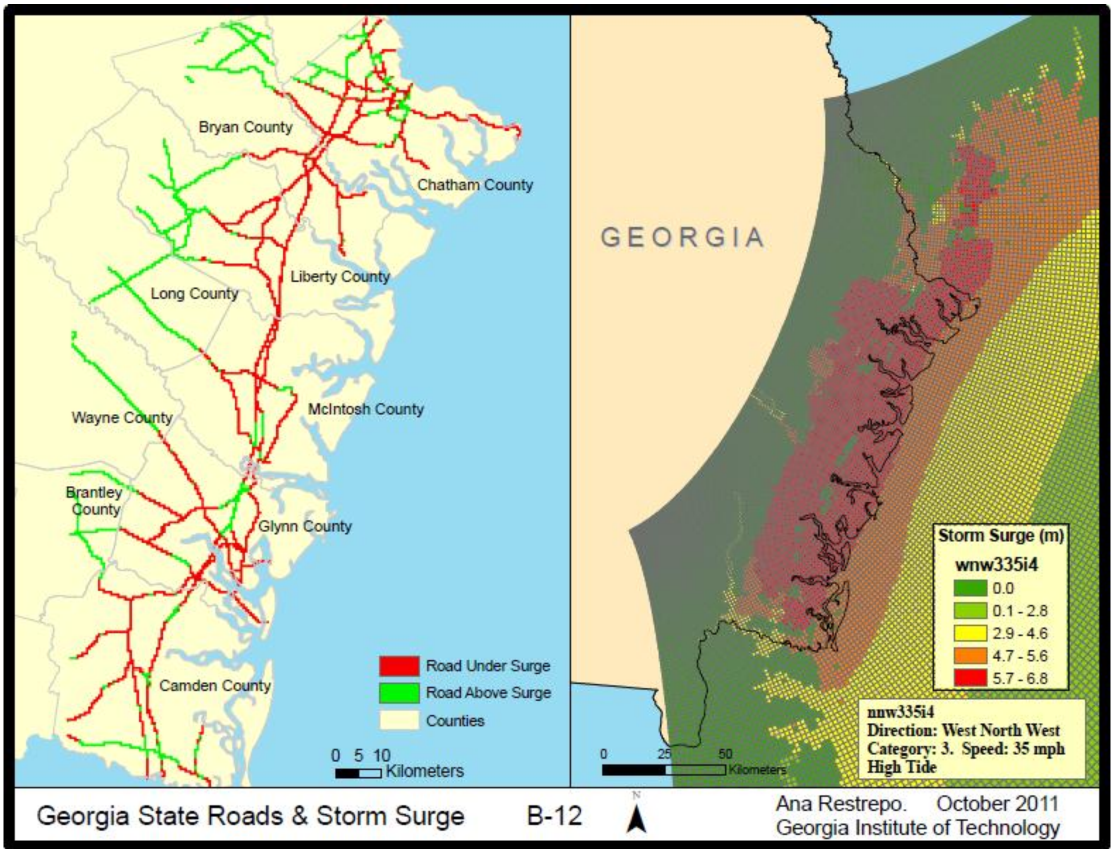


Figure 5.7: WNW335i4 Georgia State Roads & Storm Surge (see appendix B-12)

Table 5.10: Length of State Roads under Surge, WNW335i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 35 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	114.77	71.32	52.0%	-6.20	0.81	-2.14
	Camden	39	171.36	106.48	69.3%	-6.14	1.00	-1.72
	Chatham	51	230.84	143.44	69.6%	-6.10	0.92	-1.90
	Glynn	127	186.99	116.20	82.0%	-6.20	0.97	-3.03
	Liberty	179	118.07	73.37	52.1%	-6.10	0.92	-1.89
	Long	183	1.41	0.87	1.4%	0.01	0.01	0.01
	McIntosh	191	149.62	92.97	88.4%	-6.11	0.97	-1.85
	Wayne	305	1.88	1.17	1.1%	-3.10	0.90	-0.93
		Total	974.93	605.82		Average length of road segments: 200 m		

Table 5.10 shows that the roads in Brantley County are not affected by this storm surge and that only a small length of the roads of Long and Wayne County are affected by the storm. Approximately 975 kilometers (606 miles) of roads in Bryan, Camden, Chatham, Glynn, Liberty, Long, and McIntosh Counties are affected by this storm. The maximum level of water above the roads elevation is about 6.20 meters (20.34 ft) and the minimum level is 1 meter (3.24 ft) under the road elevation. Table 5.10 shows that for all the segments of the roads affected by the storm surge, the average surge levels are above the road except for the roads segments of Long County that have a constant surge level of 0.01 meters above the level of road segments. The highest average surge level above the roads is found in Glynn County. This County has 187 kilometers (116mi) of roads affected by the storm with an average surge level of 3.03 meters (9.94ft) above the roads. Camden, Chatham, and Glynn Counties have the highest length of roads affected by this storm. Glynn and McIntosh County roads have the highest percent of road under surge; 82 % and 88.4%, respectively.

• Interstates, Airports, Ports, and Railroads

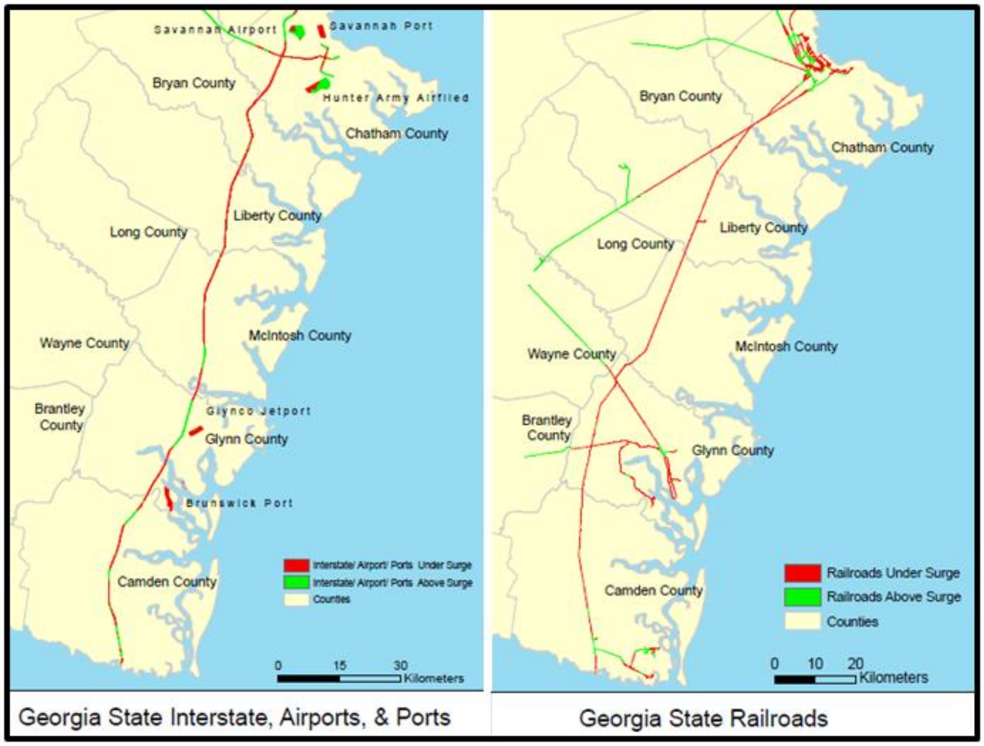


Figure 5.8 WNW335i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.8 shows that the areas assigned to Savannah and Brunswick Ports are completely under the surge, with the exception of very small areas. A small section of the area assigned for Savannah Airport is affected by the storm. This section is in the lateral of the polygon, but it tends to go to the center of the polygon. Therefore the ends of the runway in the affected area, which have lower elevations, are considered to be affected by the storm. Also, some access roads and some buildings are considered to be affected by the surge. Hunter Army Airfield is affected by the storm. Because the red section in the airports polygon is near to the center of the polygon, some infrastructures or terminals are considered to be affected. Glynco Jetport ground elevation is completely under the surge, therefore terminals and runways are subjected to the surge. See appendix B (B-13 & B-14) for a full view of the maps.

Table 5.11: Length of Interstate under Surge, WNW335i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 35 mph; High tide	16	17.72	11.01	31.0%	-4.46	0.92	-1.33
	516	4.59	2.85	42.5%	-2.13	0.65	-0.42
	95	134.49	83.57	74.7%	-6.30	1.00	-2.46
	Total	156.79	97.42		Average length of road segments: 100 m		

Approximately 157 kilometers (97 miles) out of 248 kilometers (131 mi) of interstate roads are affected by this storm surge. The maximum level of water above the interstate road is about 6.30 meters (20.67 ft); this level is found on Interstate 95. The minimum level is 1 meter (3.28 ft) under the interstate road elevation. Table 5.11 shows that for all the segments of interstates affected by the storm surge, the average surge levels are above the road. The average surge levels above the interstate roads vary from 0.42 meters up to 2.46 meters. Interstate 95 has the highest percent of road under surge, 74.7%.

Table 5.12: Length of Railroads under Surge, WNW335i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 3; Speed: 35 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	25.67	15.95	41.5%	-5.17	0.74	-2.00
	Camden	39	61.45	38.19	69.8%	-5.90	0.90	-1.75
	Chatham	51	198.18	123.14	68.4%	-5.95	0.97	-2.14
	Glynn	127	132.40	82.27	93.7%	-6.20	0.78	-2.61
	Liberty	179	43.95	27.31	64.3%	-5.05	0.94	-1.81
	Long	183	none	none	none	none	none	none
	McIntosh	191	31.07	19.31	100.0%	-5.09	0.63	-1.82
	Wayne	305	1.66	1.03	1.1%	-2.10	-1.10	-1.77
		Total	494.39	307.20		Average length of railroad segments: 100 m		

Approximately 494 kilometers (307 miles) of railroad in Bryan, Camden, Chatham, Glynn, Liberty, McIntosh, and Wayne Counties are affected by this storm.

Railroads of Brantley and Long Counties are not affected by the storm surge. A small section of Wayne County railroads are affected, 1.66 kilometers. The maximum level of water above the railroads is 6.20 meters (20.34 ft) and the minimum level is 0.94 meters (3.08 ft) under the railroad elevation. Table 5.12 shows that for all the segments of the railroads affected by the storm surge, the average surge levels are above the railroads track elevations. The average surge levels start at 1.77 meters and go up to 2.61 meters above the elevation of the railroad. Table 5.12 shows that 100% of the railroads of McIntosh County are under surge, while Glynn County has 93.7% under surge. Camden, Chatham, and Liberty Counties have very similar percentage of railroads under surge, 69.8%, 68.4%, and 64.3%, respectively.

5.2 West North-West Category 4

5.2.1 Hypothetical Storm: WNW Category 4, Forward Speed 05 mph or 8.05 km/hr, and High Tide

(WNW405i4)

- State Roads

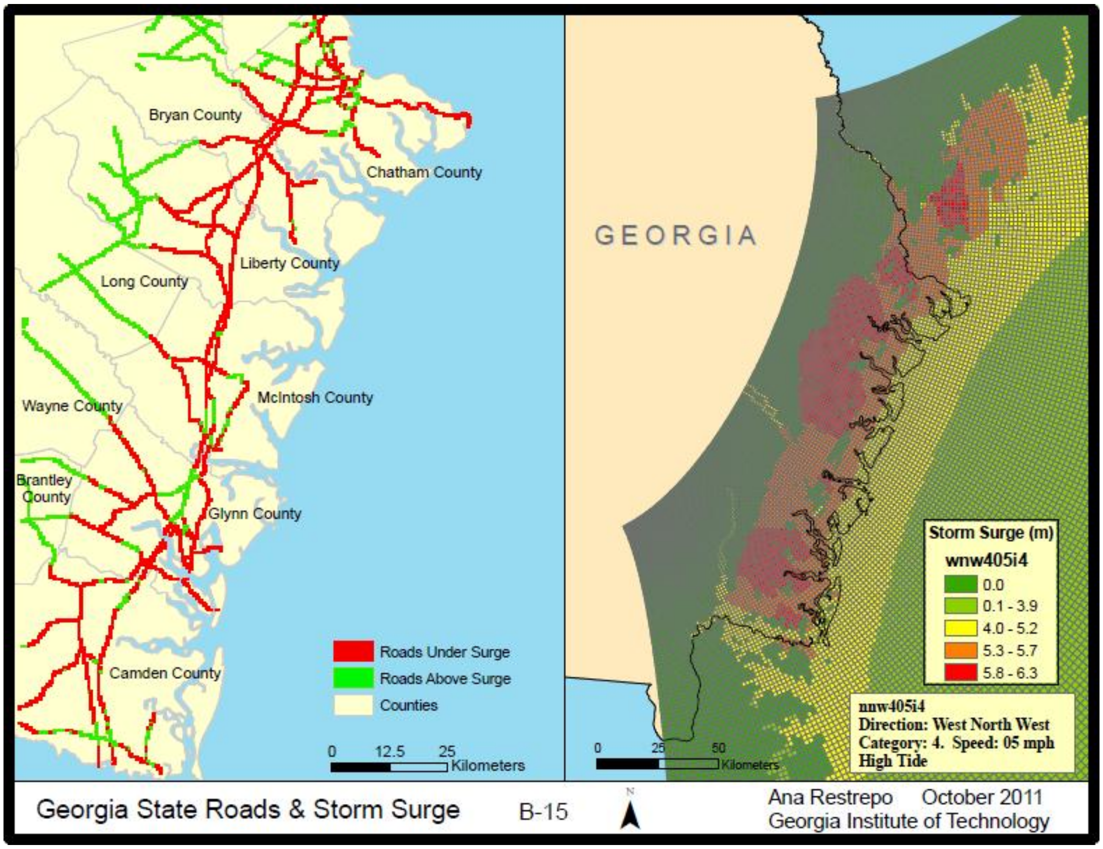


Figure 5.9: WNW405i4 Georgia State Roads & Storm Surge (see appendix B-15)

Table 5.13: Length of State Roads under Surge, WNW405i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 05 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	109.58	68.09	49.6%	-5.90	0.98	-2.04
	Camden	39	195.22	121.31	78.9%	-6.00	1.00	-1.79
	Chatham	51	255.76	158.93	77.1%	-5.90	0.99	-1.87
	Glynn	127	193.19	120.05	84.7%	-5.74	0.89	-2.42
	Liberty	179	121.65	75.60	53.6%	-5.70	0.81	-1.96
	Long	183	1.41	0.87	1.4%	0.01	0.01	0.01
	McIntosh	191	143.52	89.19	84.8%	-5.51	0.97	-1.48
	Wayne	305	1.25	0.78	0.7%	-2.60	-0.60	-1.35
		Total	1021.59	634.81		Average length of road segments: 200 m		

Table 5.10 shows that the roads in Brantley County are not affected by this storm surge and that only a small length of the roads of Long and Wayne Counties are affected by the storm. Approximately 1022 kilometers (635 miles) of roads in Bryan, Camden, Chatham, Glynn, Liberty, Long, and McIntosh Counties are affected by this storm. The maximum level of water above the roads is about 6 meters (19.685ft) and the minimum level is 1 meter (3.24ft) under the road elevation. Table 5.13 shows that for all the segments of the roads affected by the storm surge the average surge levels are above the road except for the road segments of Long County that have a constant surge level of 0.01 meters (0.39in) above the level of road segments. The highest average surge level above the roads is found in Glynn County. Glynn and McIntosh County roads have the higher percent of road under surge, 84.7 % and 84.8%, respectively.

- Interstates, Airports, Ports, and Railroads

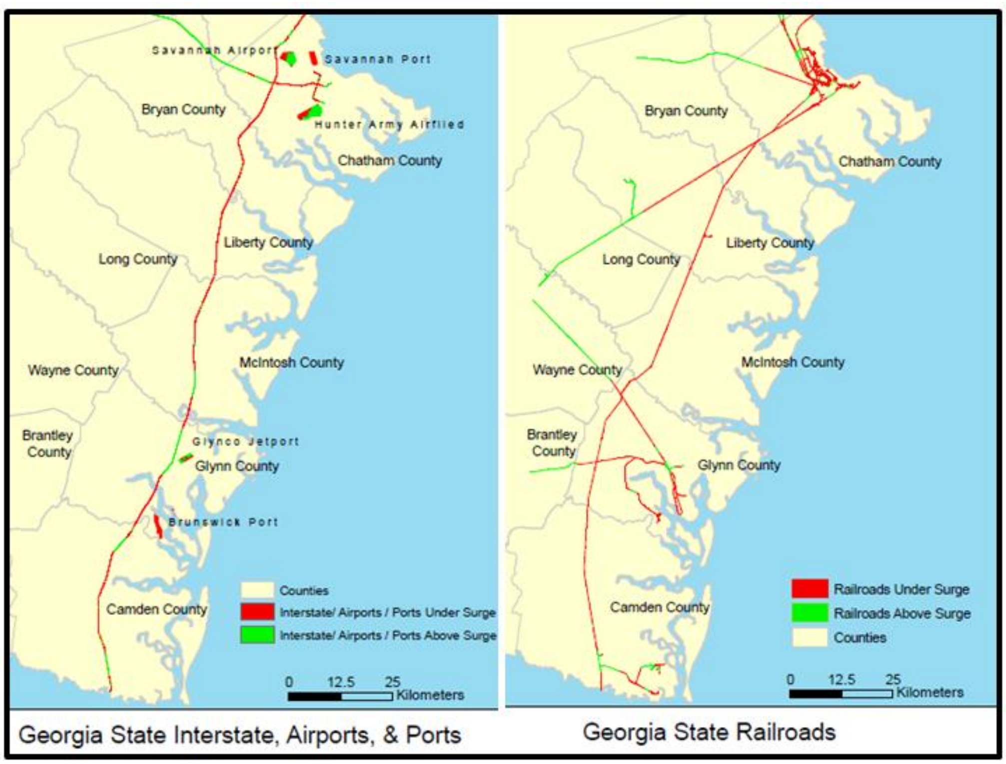


Figure 5.10: WNW405i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.10 shows that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. Some sections of the area assigned for Savannah Airport are affected by the storm. The ends of the runway that have lower elevation as well as access roads and some buildings are considered to be affected by the storm. Hunter Army Airfield is affected by the storm. Because the red section in the airport polygon is near the center of the polygon, some sections of infrastructure or terminals are considered to be affected. Glynco Jetport ground elevation is completely under the surge, terminals and runways are subjected to the surge. See appendix B (B-16 & B-17) for a full view of the maps.

Table 5.14: Length of Interstate under Surge, WNW405i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 05 mph; High tide	16	15.09	9.38	26.4%	-4.56	0.33	-1.73
	516	7.64	4.74	70.8%	-3.75	0.35	-0.97
	95	141.17	87.72	78.4%	-6.10	0.99	-2.22
	Total	163.90	101.84		Average length of road segments: 100 m		

Approximately 164 kilometers (102miles) out of 248 kilometers (131miles) of interstate roads are affected by the storm surge. The maximum level of water above the interstate road is about 6.10 meters (20ft) and the minimum level is 0.99 meters (3.24ft) under the interstate road elevation. The maximum surge level is found in Interstate 95. Table 5.14 shows that for all the segments of interstate roads affected by the storm surge the average surge levels are above the road. The average surge levels above the interstate roads goes from 0.97 meters (3.18ft) up to 2.22 meters (7.28ft). Interstate 95 and 516 have the highest percent of road under surge, 78.4% and 70.8%, respectively.

Table 5.15: Length of Railroads under Surge, WNW405i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 05 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	25.67	15.95	41.5%	-5.07	0.64	-2.04
	Camden	39	65.40	40.64	74.3%	-5.90	0.98	-1.67
	Chatham	51	251.40	156.21	86.8%	-5.90	0.98	-2.23
	Glynn	127	128.92	80.11	91.2%	-5.60	0.87	-2.05
	Liberty	179	46.55	28.93	68.1%	-5.19	0.12	-1.94
	Long	183	none	none	none	none	none	none
	McIntosh	191	30.96	19.23	99.6%	-4.79	0.15	-1.65
	Wayne	305	1.66	1.03	1.1%	-1.60	-0.60	-1.27
		Total	550.57	342.10		Average length of railroad segments: 100 m		

Figure 5.10 (right) and table 5.15 show that the railroads of Brantley and Long Counties are not affected by this storm surge. Approximately 551 kilometers (342 miles) of railroads in the other 7 counties are affected by this storm. The maximum level of water above the railroads is about 5.9 meters (19.36ft) found in Camden County. The minimum level is 0.98 meters (3.21ft) under the road elevation. Table 5.15 shows that for all the segments of the railroads affected by the storm surge the average surge levels are above the railroads track elevation. The average surge elevation varies along the counties from 1.27 meters (4.16ft) to 2.23 meters (7.31ft). Glynn and McIntosh County railroads have the highest percent of railroad under surge, 91.2% and 99.6%, respectively.

5.2.2 Hypothetical Storm: WNW Category 4, Forward Speed 15 mph or 8km/hr, and High Tide

(WNW415i4)

- State Roads

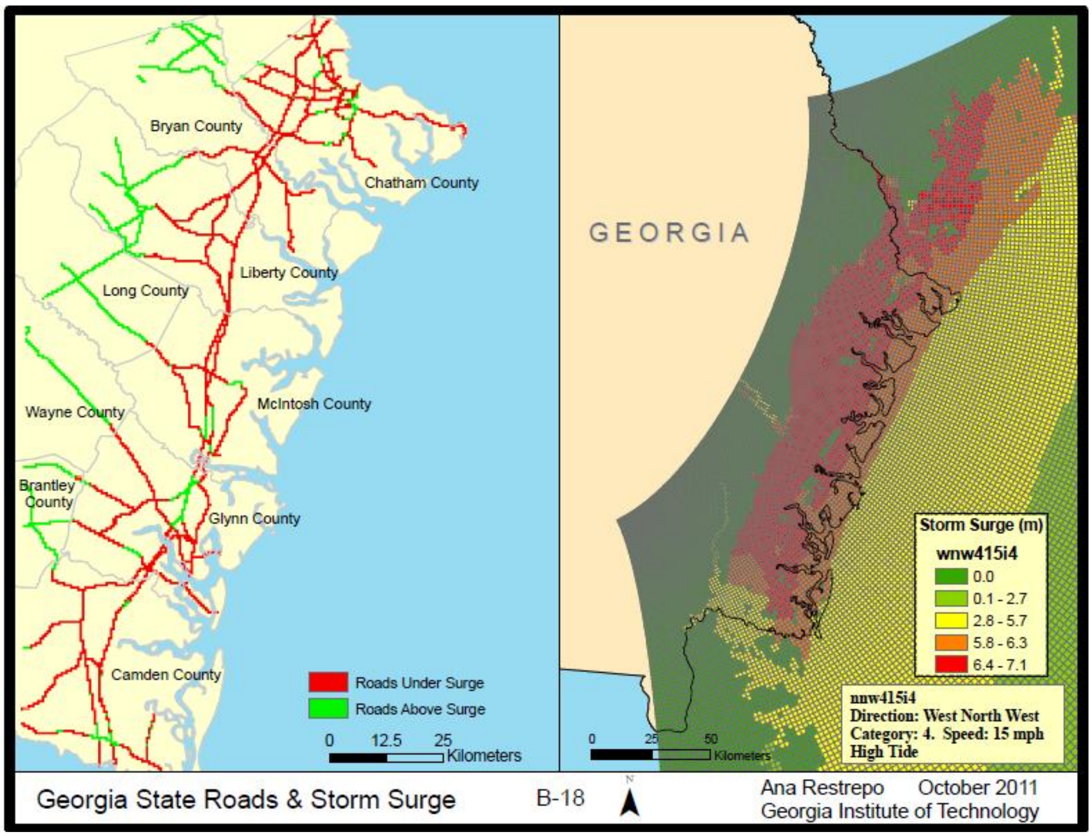


Figure 5.11: WNW415i4 Georgia State Roads & Storm Surge (see appendix B-18)

Table 5.16: Length of State Roads under Surge, WNW415i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate) (Km)	(miles)	% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m: Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 15 mph; High tide	Brantley	25	1.12	0.70	0.7%	-2.5	0.5	-0.5
	Bryan	29	114.81	71.34	52.0%	-6.90	0.41	-2.74
	Camden	39	211.80	131.61	85.6%	-6.60	1.00	-1.90
	Chatham	51	294.57	183.04	88.8%	-6.90	0.90	-2.30
	Glynn	127	196.19	121.91	86.0%	-6.60	0.97	-3.22
	Liberty	179	122.93	76.39	54.2%	-6.50	0.34	-2.59
	Long	183	2.45	1.52	2.5%	-0.69	0.49	-0.26
	McIntosh	191	154.15	95.79	91.0%	-6.41	0.97	-2.14
	Wayne	305	1.88	1.17	1.1%	-3.70	0.30	-1.52
		Total	1099.89	683.47		Average length of road segments: 200 m		

All 9 counties analyzed have roads affected by this storm. Wayne, Long, and Brantley County roads have the smallest section of roads affected. Brantley County has 0.7% of its roads under surge, Long County 2.5%, and Wayne County 1.1%. Approximately 1100 kilometers (684 miles) of road are affected by this storm. The maximum level of water above the roads is about 6.9 meters (22.64ft) and the minimum level is 1 meter (3.2ft) under the road elevation. Table 5.16 shows that for all the segments of the roads affected by the storm surge the average surge levels are above the road. The average surge levels start at 0.5 meters (1.64ft) and go up to 2.79 meters (9.15ft) above the elevation of the roads. Glynn, Camden, Chatham, and McIntosh Counties have a similar percentage of road under surge, 86%, 85.6%, 88.8%, and 91%, respectively. These counties have the highest percent of road under surge.

- Interstates, Airports, Ports, and Railroads

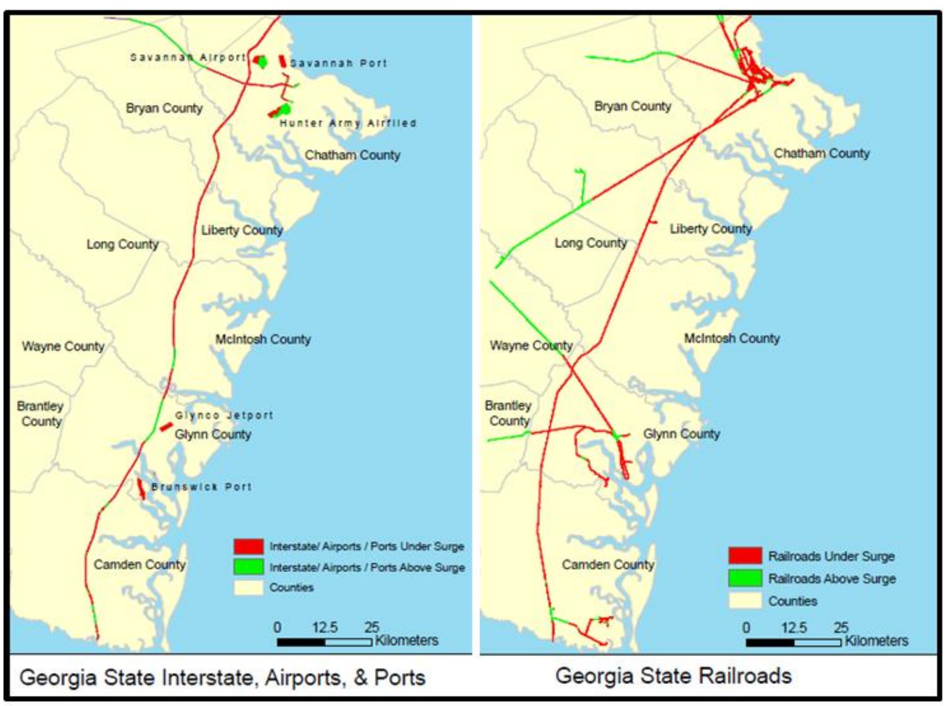


Figure 5.12: WNW415i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.12 shows that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. Also, it can be observed that the Savannah Airport is affected by this storm. Based on the area of this airport polygon affected by the storm access roads, some buildings and some small sections of the runway are considered to be affected by the storm. Hunter Army Airfield is also affected by the storm. Access roads and others infrastructures are considered to be affected. Glynco Jetport ground elevation is completely under the surge and therefore terminals and runways are subjected to the surge. See appendix B (B-19 & B-20) for a full view of the maps.

Table 5.17: Length of Interstate under Surge, WNW415i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 15 mph; High tide	16	24.01	14.92	42.0%	-5.36	0.70	-1.94
	516	7.97	4.95	74.0%	-4.25	0.83	-1.37
	95	151.81	94.33	84.3%	-6.90	0.90	-2.84
	Total	183.79	114.20		Average length of road segments: 100 m		

Approximately 184 kilometers (114mi) of interstate roads are affected by the storm surge. The maximum level of water above the interstate roads is about 6.9 meters (22.6ft) and the minimum level is 0.90 meters (2.95ft) under the road elevation. Table 5.17 shows that for all the segments of interstate roads affected by the storm surge the average surge levels are more than 1 meter (3.28ft) above the road. Interstates 95 and 516 have the highest percent of road under surge: 84.3% and 74%, respectively.

Table 5.18: Length of Railroads under Surge, WNW415i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 15 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	25.67	15.95	41.5%	-6.07	-0.46	-3.03
	Camden	39	68.76	42.73	78.1%	-6.60	0.10	-2.19
	Chatham	51	259.37	161.17	89.5%	-6.55	0.07	-2.79
	Glynn	127	132.18	82.13	93.5%	-6.50	-0.02	-2.98
	Liberty	179	46.55	28.93	68.1%	-6.15	-0.78	-2.77
	Long	183	none	none	none	none	none	none
	McIntosh	191	31.07	19.31	100.0%	-5.79	0.03	-2.42
	Wayne	305	1.66	1.03	1.1%	-2.70	-1.70	-2.42
		Total	565.27	351.24		Average length of railroad segments: 100 m		

Table 5.18 shows that the railroads of Brantley and Long Counties are not affected by this storm surge. Approximately 565 kilometers (351 miles) of railroads in the other 7 counties are affected by this storm. The maximum level of water above the railroads is about 6.6 meters (21.65ft), found in Camden County. The minimum level is 10 centimeters (3.93in) under the railroad elevation. Therefore, this surge is at the same level or higher level than all the segments of the railroads affected by this storm. Table 5.18 shows that for all the segments of railroads affected by the storm surge the average surge levels are greater than 2 meters above the railroads. After McIntosh County, which has all of its railroads under surge, Glynn and Chatham Counties have the highest percent of railroads under surge: 93.5% and 83.5% respectively.

5.2.3 Hypothetical Storm: WNW Category 4, Forward Speed 25 mph or 40.2 km/hr, and High Tide

(WNW425i4)

- State Roads

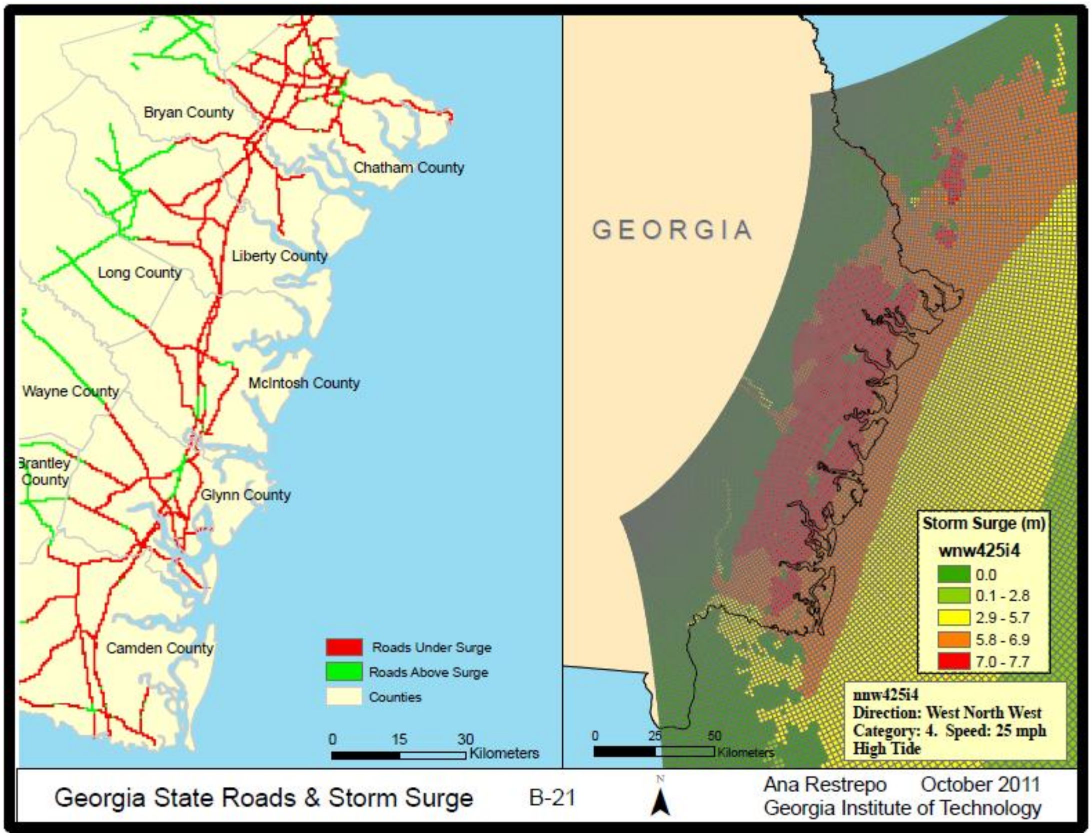


Figure 5.13: WNW425i4 Georgia State Roads & Storm Surge (see appendix B-21)

Table 5.19: Length of State Roads under Surge, WNW425i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 25 mph; High tide	Brantley	25	2.6789	1.66	1.7%	-3.60	-0.60	-1.84
	Bryan	29	114.81	71.34	52.0%	-7.30	-0.33	-3.26
	Camden	39	228.46	141.97	92.4%	-7.30	1.00	-2.16
	Chatham	51	305.75	190.00	92.1%	-7.30	0.99	-2.61
	Glynn	127	200.62	124.66	88.0%	-7.30	0.87	-3.77
	Liberty	179	124.67	77.47	55.0%	-6.90	0.61	-3.01
	Long	183	3.17	1.97	3.2%	-1.19	0.34	-0.41
	McIntosh	191	156.15	97.03	92.2%	-6.97	0.73	-2.77
	Wayne	305	1.88	1.17	1.1%	-4.60	-0.60	-2.43
		Total	1138.19	707.27		Average length of road segments: 200 m		

All 9 counties analyzed have roads affected by this storm. Wayne, Long, and Brantley County roads have the smallest section of roads affected by this storm. Brantley County has 1.7% of its roads under the surge; Long County, 3.2%; and Wayne County, 1.1%. Approximately 1138 kilometers (707 miles) of road are affected by this storm. The maximum level of water above the roads is about 7.30 meters (23.9ft) and the minimum level is 1 meter (3.2ft) under the road elevation. Table 5.19 shows that for all the segments of the roads affected by the storm surge the average surge levels are above the road and greater than 2 meters (6.56ft) except for Long County, in which the average surge level is 0.41 meters (1.35ft) above the road. Glynn, Camden, Chatham, and McIntosh Counties have highest percent of road under surge: 88%, 92.4%, 92.1%, and 92.2%, respectively.

- Interstates, Airports, Ports, and Railroads

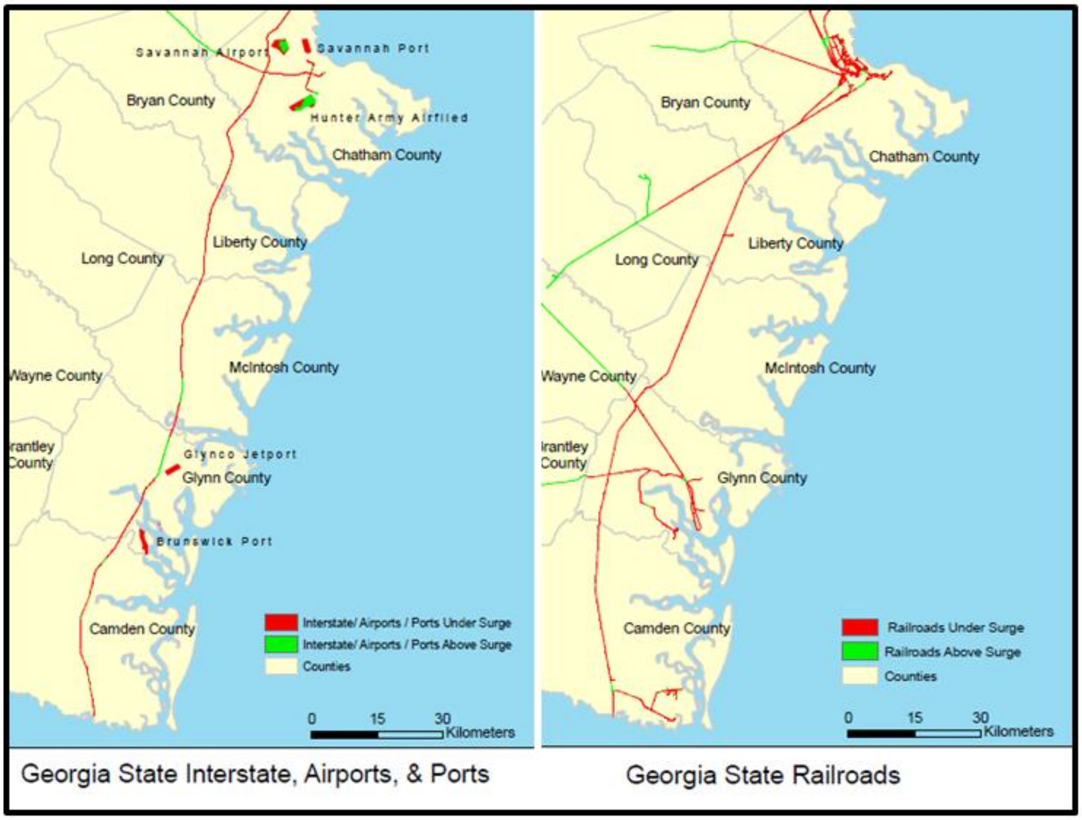


Figure 5.14: WNW425i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.14 shows that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. Also, it can be observed that Savannah Airport is affected by this storm. Its polygon has a large area in red or under surge, therefore some parts of the runway, terminal, access roads, and other infrastructures are considered to be affected by the storm. Hunter Army Airfield is affected by the storm. Because the red section in the airport polygon is near the center of the polygon, the lower sections of the runway and other infrastructures are considered to be affected. Glynco Jetport ground elevation is completely under the surge, therefore terminals and runways are subjected to the surge. See appendix B (B-22 & B-23) for a full view of the maps.

Table 5.20: Length of Interstate under Surge, WNW425i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 25 mph; High tide	16	25.36	15.76	44.3%	-5.76	0.95	-2.34
	516	8.20	5.10	76.1%	-4.45	0.64	-1.61
	95	159.72	99.25	88.7%	-7.40	1.00	-3.16
	Total	193.28	120.10		Average length of road segments: 100 m		

Approximately 193 kilometers (120 miles) of interstate roads are affected by this storm surge. The maximum level of water above the interstate is about 7.40 meters (24.27ft), found on Interstate 95. The minimum level is 1 meters (3.28ft) under the interstate road elevation. Table 5.20 shows that for all the segments of interstate roads affected by the storm surge the average surge levels are greater than 1.6 meters (5.3ft) above the roads. Interstates 95 and 516 have the highest percent of road under surge: 88.7% and 76.1%, respectively.

Table 5.21: Length of Railroads under Surge, WNW425i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 25 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	25.67	15.95	41.5%	-6.47	-0.86	-3.48
	Camden	39	81.90	50.89	93.0%	-7.40	1.00	-2.25
	Chatham	51	272.51	169.33	94.1%	-7.15	0.93	-2.91
	Glynn	127	138.55	86.09	98.0%	-7.20	0.30	-3.65
	Liberty	179	46.55	28.93	68.1%	-6.65	-1.18	-3.20
	Long	183	none	none	none	none	none	none
	McIntosh	191	31.07	19.31	100.0%	-6.69	-0.77	-3.01
	Wayne	305	1.66	1.03	1.1%	-3.60	-2.60	-3.27
		Total	597.93	371.53		Average length of railroad segments: 100 m		

Brantley and Long County railroads are not affected by this storm surge. Approximately 598 kilometers (372 miles) of railroads in the other 7 counties are affected by this storm. The maximum level of water above the railroads is about 7.40 meters (24.3ft), found in Camden County. The minimum level is 1meter (3.28ft) under the road elevation. Table 5.21 shows that for all the segments of interstate affected by the storm surge the average surge levels are greater than 2.9 (9.5ft) meters above the railroads. After McIntosh County, which has all of its railroads under surge, Glynn and Chatham Counties have the highest percent of railroad track under surge: 98% and 94.1% respectively.

5.2.4 Hypothetical Storm: WNW Category 4, Forward Speed 35 mph or 56.32 km/hr, and High Tide

(WNW435i4)

- State Roads

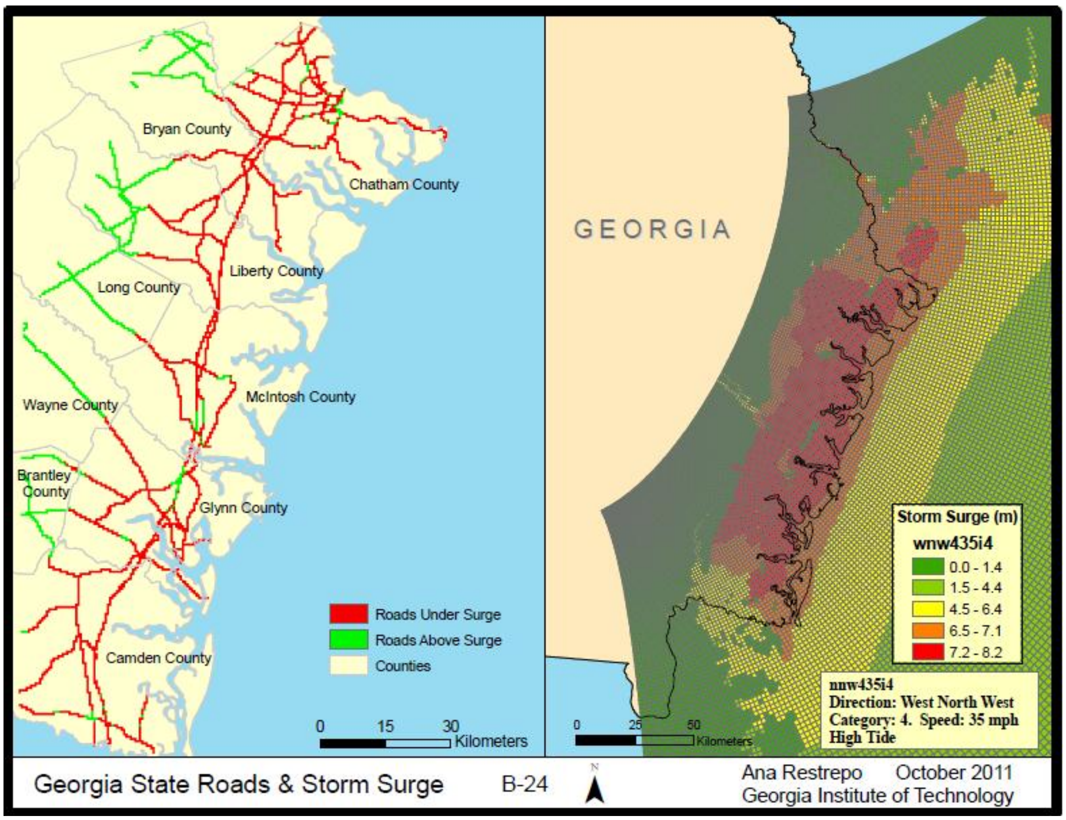


Figure 5.15: WNW435i4 Georgia State Roads & Storm Surge (see appendix B-24)

Table 5.22: Length of State Roads under Surge, WNW435i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 35 mph; High tide	Brantley	25	3.1789	1.98	2.1%	-3.70	-0.70	-1.98
	Bryan	29	114.81	71.34	52.0%	-7.30	-0.23	-3.31
	Camden	39	230.16	143.02	93.0%	-7.34	1.00	-2.25
	Chatham	51	306.35	190.37	92.3%	-7.30	0.95	-2.71
	Glynn	127	203.40	126.39	89.2%	-7.50	0.94	-4.01
	Liberty	179	124.67	77.47	55.0%	-7.00	0.81	-3.04
	Long	183	3.17	1.97	3.2%	-1.29	0.34	-0.50
	McIntosh	192.5	157.85	98.09	93.2%	-7.37	0.98	-3.01
	Wayne	305	1.88	1.17	1.1%	-4.90	-0.90	-2.73
		Total	1145.47	711.80		Average length of road segments: 200 m		

Table 5.22 shows that all of the counties have roads affected by this storm. Wayne, Long, and Brantley County roads have the smallest section of roads affected by this storm. Brantley County has 2.1% of its roads under the surge; Long County, 3.2%; and Wayne County, 1.1%. Approximately 1145 kilometers (712 miles) of road are affected by this storm. The maximum level of water above the roads is about 7.5 meters (24.6ft) and the minimum level is 1 meter (3.2ft) under the road elevation. Also, Table 5.22 shows that for all the segments of the roads affected by the storm surge the average surge levels are above the road and greater than 2 meters (6.56ft) except for Long County where the average surge level is 0.5 meters (1.64ft) above the road. Glynn, Camden, Chatham, and McIntosh Counties have the highest percent of road under surge: 89.2%, 93%, 92.3%, and 93.2%, respectively.

- Interstates, Airports, Ports, and Railroads

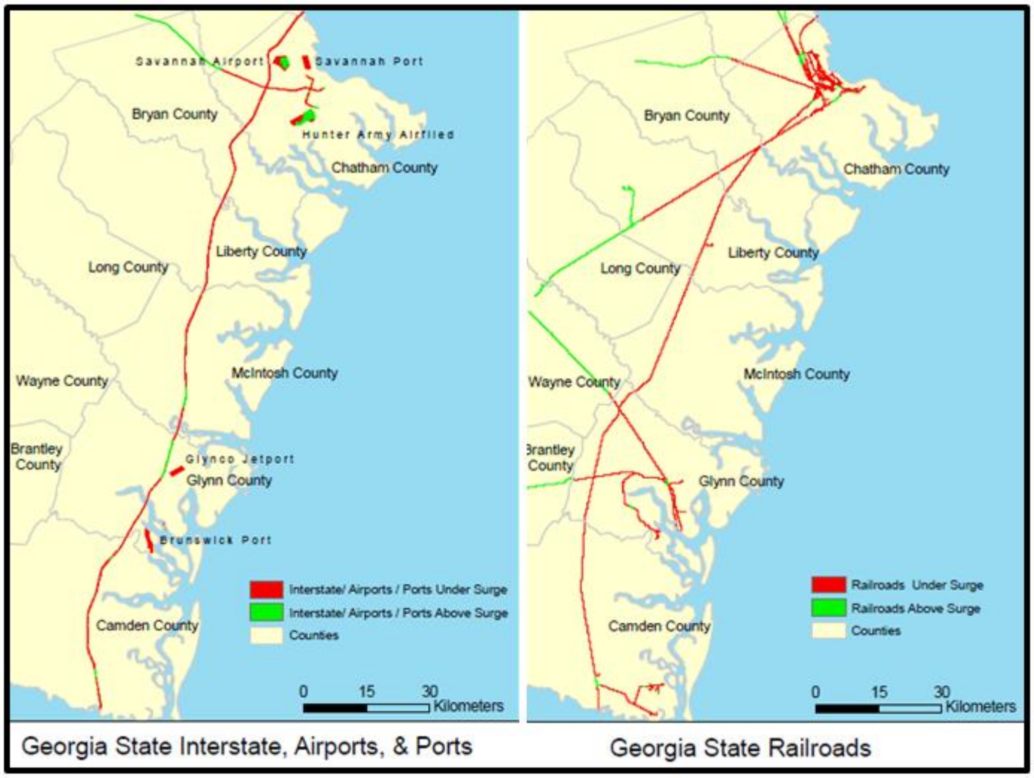


Figure 5.16: WNW435i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.16 shows that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. Also, it can be observed that the Savannah Airport is affected by this storm. Its polygon has a large area under surge, therefore some parts of the runway, terminal, access roads, and other infrastructures are considered to be affected by the storm. Hunter Army Airfield is affected by the storm. Because the red section in the airport polygon is near the center of the polygon, the lower sections of the runway and other infrastructures are considered to be affected. Glynco Jetport ground elevation is completely under the surge, therefore terminals and runways are subject to the surge. See appendix B (B-25 & B-26) for a full view of the maps.

Table 5.23: Length of Interstate under Surge, WNW435i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 35 mph; High tide	16	25.36	15.76	44.3%	-5.86	0.95	-2.37
	516	8.20	5.10	76.1%	-4.45	0.34	-1.70
	95	162.03	100.68	90.0%	-7.70	1.00	-3.23
	Total	195.60	121.54		Average length of road segments: 100 m		

Approximately 196 kilometers (122 mi) of interstate roads are affected by the storm surge. The maximum level of water above the interstate is about 7.70 meters (25.26ft), found on Interstate 95. The minimum level is 1 meter (3.28ft) under the interstate road elevation. Table 5.23 shows that for all the segments of interstate roads affected by the storm surge the average surge levels are above the road and greater than 1.7 meters (5.6ft) above the roads. Interstates 95 and 516 have the highest percent of road under surge: 90% and 76.1%, respectively.

Table 5.24: Length of Railroads under Surge, WNW435i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 4; Speed: 35 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	25.67	15.95	41.5%	-6.47	-0.96	-3.43
	Camden	39	81.57	50.68	92.6%	-7.60	1.00	-2.42
	Chatham	51	272.84	169.54	94.2%	-7.25	0.99	-2.97
	Glynn	127	138.55	86.09	98.0%	-7.40	-0.02	-3.90
	Liberty	179	46.55	28.93	68.1%	-6.65	-1.08	-3.22
	Long	183	none	none	none	none	none	none
	McIntosh	191	31.07	19.31	100.0%	-6.89	-0.87	-3.15
	Wayne	305	1.66	1.03	1.1%	-3.90	-2.90	-3.57
		Total	597.93	371.53		Average length of railroad segments: 100 m		

Brantley and Long County railroads are not affected by this storm surge. Approximately 598 kilometers (372 miles) of railroads of the other 7 counties are affected by this storm. The maximum level of water above the Railroads is about 7.60 meters (24.93ft). This level is found in Camden County. The minimum level is 1meter (3.28ft) under the road elevation. Table 5.24 shows that for all the segments of interstate affected by the storm surge the average surge levels are greater than 2.9 (9.5ft) meters above the railroads. After McIntosh County which has all its railroads under surge, Glynn, Camden, and Chatham Counties have the highest percent of railroad under surge: 98%, 92.6%, and 94.2%, respectively.

5.3 West North-West Category 5

5.3.1 Hypothetical Storm: WNW Category 5, Forward Speed 05 mph or 8 km/hr, and High Tide

(WNW505i4)

- State Roads

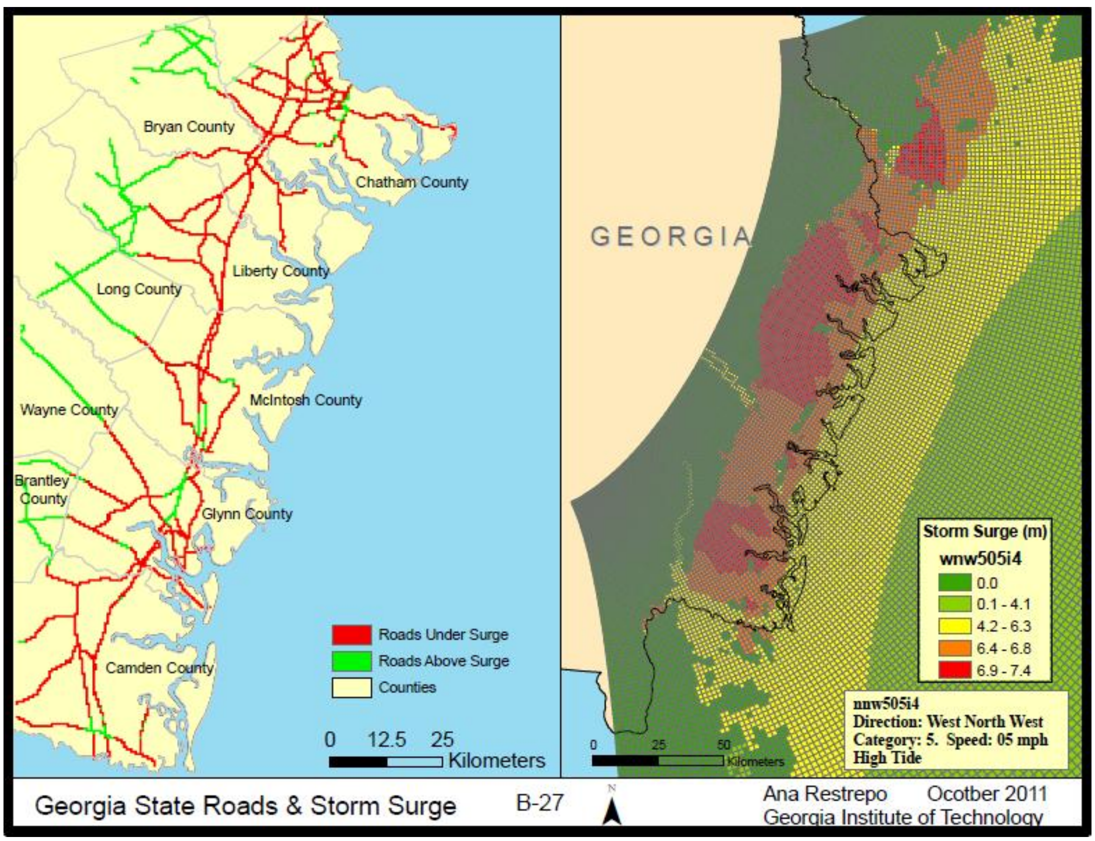


Figure 5.17: WNW505i4 Georgia State Roads & Storm Surge (see appendix B-27)

Table 5.25: Length of State Roads under Surge, WNW505i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate) (Km)	Length of Road Under Surge (Include Interstate) (miles)	% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m: Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 05 mph; High tide	Brantley	25	1.12	0.70	0.7%	-2.70	0.30	-0.70
	Bryan	29	114.81	71.34	52.0%	-7.00	0.21	-2.97
	Camden	39	219.46	136.37	88.7%	-7.00	1.00	-2.37
	Chatham	51	308.42	191.66	92.9%	-7.00	0.86	-2.56
	Glynn	127	190.84	118.58	83.7%	-6.84	0.87	-3.31
	Liberty	179	125.68	78.10	55.4%	-6.80	0.71	-2.98
	Long	183	3.61	2.24	3.7%	-1.29	0.14	-0.62
	McIntosh	191	157.85	98.09	93.2%	-6.57	0.97	-2.31
	Wayne	305	1.92	1.19	1.1%	-3.70	0.30	-1.53
		Total	1123.71	698.27		Average length of road segments: 200 m		

Table 5.25 shows that all the counties analyzed have roads affected by this storm. Wayne, Long, and Brantley County roads have the smallest section of roads affected by this storm. Brantley County has 0.7% of its roads under the surge; Long County 3.7%; and Wayne County 1.1%. Approximately 1124 kilometers (698 miles) of road are affected by this storm. The maximum level of water above the roads is about 7 meters (23ft) and the minimum level is 1 meter (3.2ft) under the road elevation. In all the segments of the roads affected by the storm surge, the average surge levels are above the road. Glynn, Camden, Chatham, and McIntosh Counties have the highest percent of road under surge: 83.7%, 88.7%, 92.9%, and 93.2%, respectively.

- Interstates, Airports, Ports, and Railroads

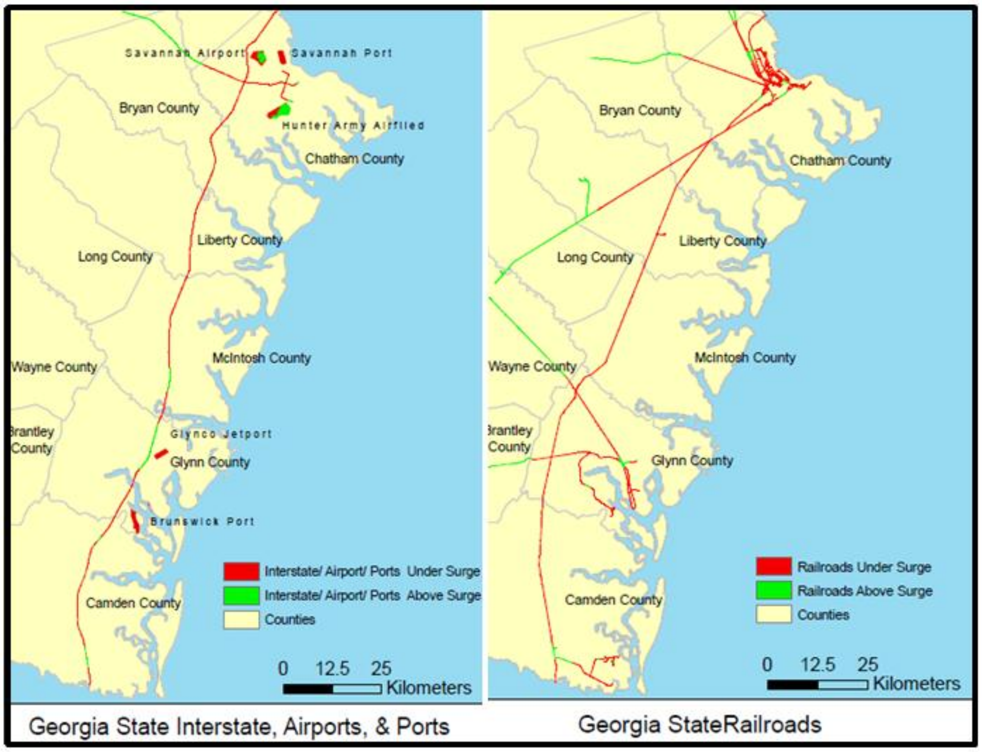


Figure 5.18: WNW505i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.18 shows that the Savannah Airport is affected by this storm. Its polygon has a large area under surge, therefore some parts of the runway, terminal, access roads, and other infrastructures are considered to be affected by the storm. Hunter Army Airfield is affected by the storm. Because the red section in the airports polygon is near the center of the polygon, the lower sections of the runway and other infrastructures are considered to be affected. Glynco Jetport ground elevation is completely under the surge, therefore terminals, and runways are subjected to the surge. From Figure 5.18 it can be observed that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. See appendix B (B-25 & B-26) for a full view of the maps.

Table 5.26: Length of Interstate under Surge, WNW505i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 05 mph; High tide	16	25.36	15.76	44.3%	-5.58	0.65	-2.27
	516	8.32	5.17	77.2%	-4.75	0.77	-1.86
	95	154.12	95.77	85.6%	-7.00	1.00	-3.06
	Total	187.80	116.69		Average length of road segments: 100 m		

Approximately 188 kilometers (117 miles) of interstate roads are affected by this storm surge. The maximum level of water above the interstate is about 7 meters (23ft), found on Interstate 95. The minimum level is 1 meters (3.28ft) under the interstate road elevation. Table 5.26 shows that for all the segments of interstate roads affected by the storm surge the average surge levels are above the road and greater than 1.8 meters (5.9ft) above the roads. Interstates 95 and 516 have the higher percent of road under surge: 85.6% and 77.2%, respectively.

Table 5.27: Length of Railroads under Surge, WNW505i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 05 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	25.67	15.95	41.5%	-6.27	-0.56	-3.22
	Camden	39	76.42	47.49	86.8%	-7.00	0.86	-2.28
	Chatham	51	273.26	169.80	94.3%	-6.90	0.99	-3.07
	Glynn	127	133.35	82.86	94.3%	-6.70	1.00	-3.06
	Liberty	179	46.55	28.93	68.1%	-6.35	-1.08	-3.12
	Long	183	none	none	none	none	none	none
	McIntosh	191	31.07	19.31	100.0%	-5.79	-0.07	-2.68
	Wayne	305	1.66	1.03	1.1%	-2.70	-1.70	-2.37
		Total	587.99	365.36		Average length of railroad segments: 100 m		

Brantley and Long County railroads are not affected by this storm surge. Approximately 588 kilometers (365 miles) of railroads of the other 7 counties are affected by this storm. The maximum level of water above the railroads is about 7meters (23ft). This level is found in Camden County. The minimum level is 1meter (3.28ft) under the railroad elevation. Table 5.27 shows that Bryan, Liberty, McIntosh, and Wayne Counties railroad segments affected by this storm are all under the surge. Also, this table shows that for all the segments of interstate affected by the storm surge the average surge levels are greater than 2.2 (7.21ft) meters above the railroads tracks. After McIntosh County, which has all its railroads under surge, Glynn, Camden, and Chatham Counties have the highest percent of Railroad under surge: 94.3%, 86.8%, and 94.3%, respectively.

5.3.2 Hypothetical Storm: WNW Category 5, Forward Speed 15 mph or 24.14 km/hr, and High Tide

(WNW515i4)

- State Roads

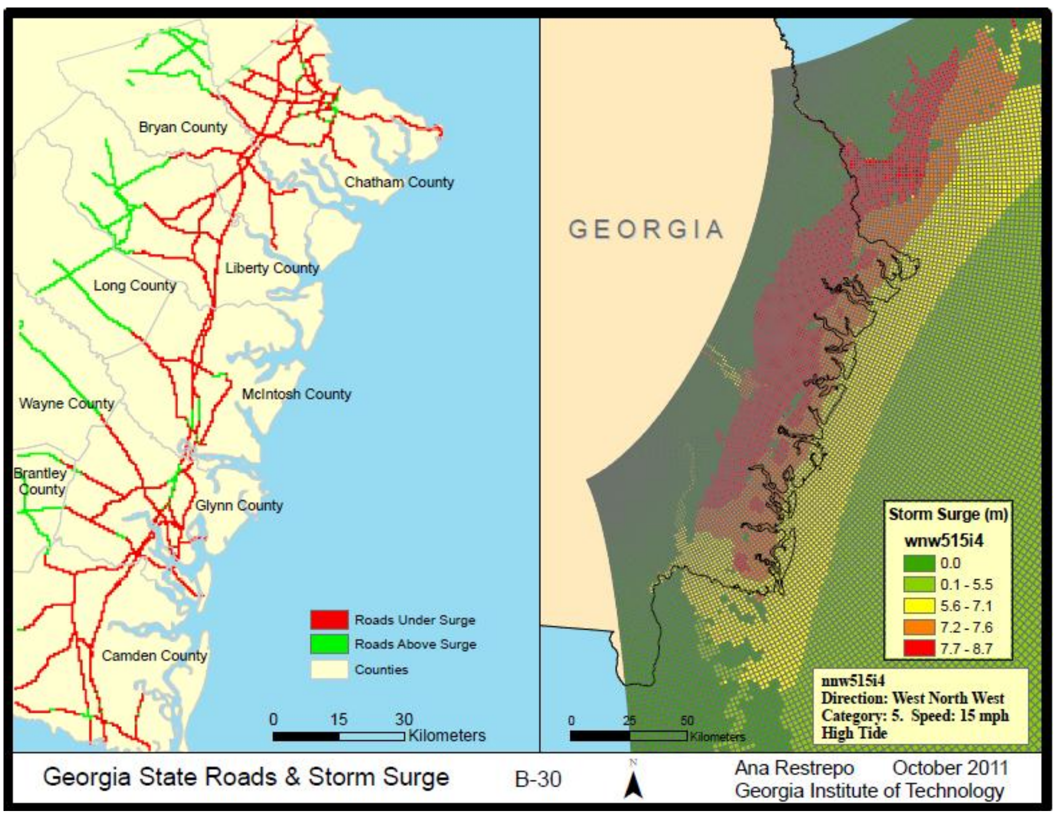


Figure 5.19: WNW515i4 Georgia State Roads & Storm Surge (see appendix B-30)

Table 5.28: Length of State Roads under Surge, WNW515i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 15 mph; High tide	Brantley	25	3.18	1.98	2.1%	-4.20	-1.20	-2.53
	Bryan	29	119.61	74.33	54.2%	-8.00	0.48	-3.79
	Camden	39	232.25	144.32	93.9%	-7.90	0.96	-2.57
	Chatham	51	310.15	192.73	93.5%	-8.00	0.87	-3.34
	Glynn	127	205.40	127.63	90.0%	-7.90	0.90	-4.04
	Liberty	179	127.27	79.09	56.1%	-7.60	-0.59	-3.72
	Long	183	3.17	1.97	3.2%	-1.89	-0.34	-1.01
	McIntosh	191	159.85	99.33	94.4%	-7.41	0.88	-3.14
	Wayne	305	2.28	1.42	1.3%	-5.00	-1.00	-2.83
		Total	1163.17	722.79		Average length of road segments: 200 m		

Table 5.28 shows that all the counties analyzed have roads affected by this storm. Wayne, Long, and Brantley County roads have the smallest sections of roads affected by this storm. Approximately 1162 kilometers (723 miles) of road are affected by this storm. The maximum level of water above the roads is about 8 meters (26.2ft) and the minimum level is 1 meter (3.28ft) under the road elevation. In all the segments of the roads affected by the storm surge, the average surge levels are above the road. Table 5.28 also shows that Brantley, Liberty, Long, and Wayne County road segments affected by this storm are all under the surge. Glynn, Camden, Chatham, and McIntosh Counties have highest percent of road under surge: 90%, 93.9%, 93.5%, and 93.8%, respectively.

- Interstates, Airports, Ports, and Railroads

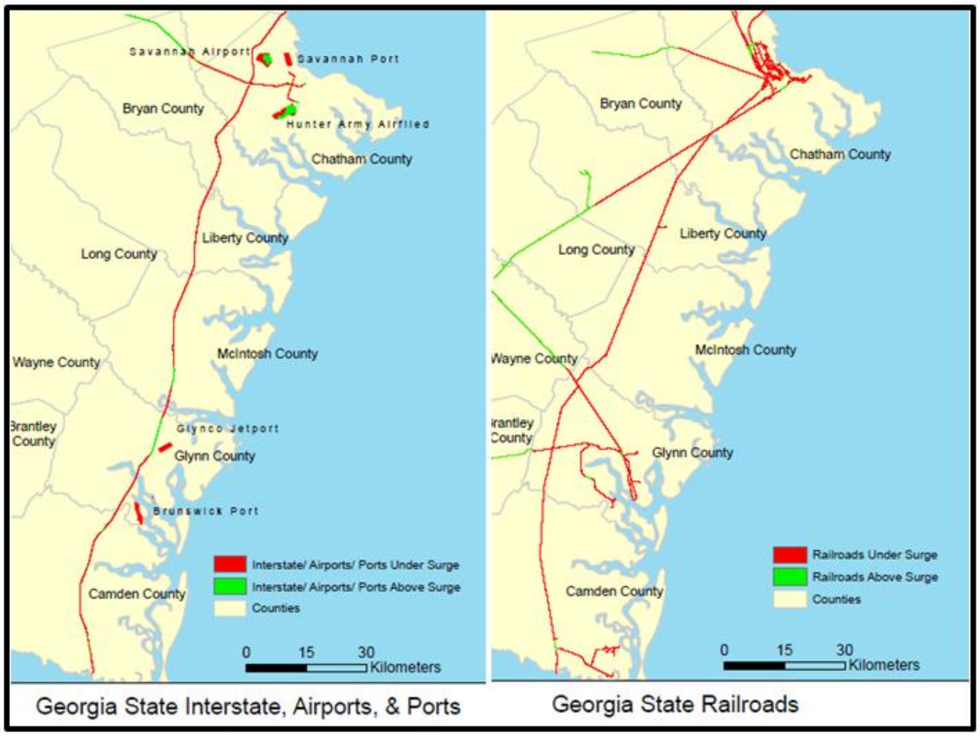


Figure 5.20: WNW515i4 Georgia State Interstates, Airports, Ports, and Railroads

From Figure 5.20 it can be observed that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. Also, it can be observed that the Savannah Airport is affected by this storm. Its polygon has a large area under surge, therefore some parts of the runway, terminal, access roads, and other infrastructures are considered to be affected by the storm. Hunter Army Airfield is affected by the storm. Because the red section in the airport polygon is near the center of the polygon, the lower sections of the runway, road access, and other infrastructures are considered to be affected. Glynco Jetport ground elevation is completely under the surge, therefore terminals and runways are subjected to the surge. See appendix B (B-31 & B-31) for a full view of the maps.

Table 5.29: Length of Interstate under Surge, WNW515i4

Storm	Interstate Name	Length of Interstate Under Surge (Km)	Length of Interstate Under Surge (miles)	% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m: Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 15 mph; High tide	16	30.19	18.76	52.8%	-6.56	0.74	-2.68
	516	8.55	5.32	79.4%	-5.45	0.51	-2.44
	95	162.59	101.03	90.3%	-8.00	0.90	-3.71
	Total	201.34	125.11		Average length of road segments: 100 m		

Table 5.29 shows that 201 kilometers (125 miles) of interstate roads are affected by this storm surge. The maximum level of water above the interstate is about 8 meters (26.3ft), found on Interstate 95. The minimum level is 0.90 meters (2.95ft) under the interstate road elevation. Also, Table 5.29 shows that for all the segments of interstate roads affected by the storm surge the average surge levels are above the road and greater than 2.4 meters (7.87ft) above the roads. Interstates 95 and 516 have the highest percent of road under surge: 90.3% and 79.4%, respectively.

Table 5.30: Length of Railroads under Surge, WNW515i4

Storm	County	County Code	Length of Railroad Under Surge (Km)	Length of Railroad Under Surge (miles)	% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m: Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 15 mph; High tide	Brantley	25	none	none	none	none	none	none
	Bryan	29	26.00	16.16	42.0%	-7.17	0.61	-4.08
	Camden	39	82.97	51.55	94.2%	-7.90	1.00	-2.78
	Chatham	51	274.31	170.45	94.7%	-7.75	0.96	-3.85
	Glynn	127	138.55	86.09	98.0%	-7.70	0.00	-4.04
	Liberty	179	47.70	29.64	69.8%	-7.35	-1.52	-3.89
	Long	183	none	none	none	none	none	none
	McIntosh	191	31.07	19.31	100.0%	-7.09	-1.17	-3.53
	Wayne	305	1.66	1.03	1.1%	-4.00	-3.00	-3.67
		Total	602.26	374.23		Average length of railroad segments: 100 m		

Table 5.30 shows that Brantley and Long County railroads are not affected by this storm surge. Approximately 602 kilometers (374 miles) of railroads of the other 7 counties are affected by this storm. The maximum level of water above the railroads is about 7.9meters (25.9ft), found on Camden County. The minimum level is 1meter (3.28ft) under the railroad elevation. Table 5.27 shows that Liberty, McIntosh, and

Wayne Counties railroad segments affected by this storm are all under the surge levels. Also, this table shows that for all the segments of interstate affected by the storm surge the average surge levels are greater than 2.78 (9.12ft) meters above the railroads. After McIntosh County, which has all its railroads under surge, Glynn, Camden, and Chatham Counties have the highest percent of railroad under surge: 98%, 94.2%, and 94.7%, respectively.

5.3.3 Hypothetical Storm: WNW Category 5, Forward Speed 25 mph or 40.2 km/hr, and High Tide

(WNW525i4)

- State Roads

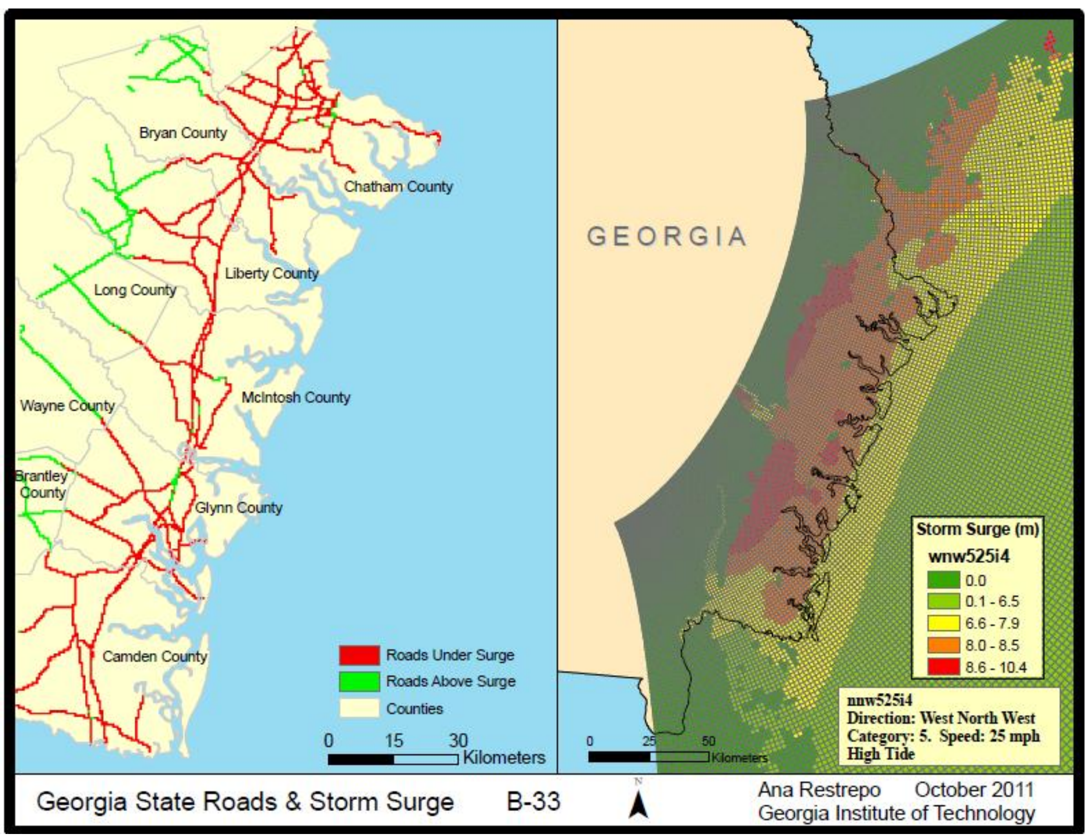


Figure 5.23: WNW525i4 Georgia State Roads & Storm Surge (see appendix B-33)

Table 5.31: Length of State Roads under Surge, WNW525i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate)		% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 25 mph; High tide	Brantley	25	3.18	1.98	2.1%	-5.6	-2.6	-3.8266
	Bryan	29	120.61	74.95	54.6%	-8.40	0.12	-4.20
	Camden	39	242.65	150.79	98.1%	-8.40	0.90	-3.17
	Chatham	51	313.25	194.66	94.4%	-8.40	0.75	-3.68
	Glynn	127	211.17	131.22	92.6%	-8.90	0.66	-4.84
	Liberty	179	129.57	80.52	57.1%	-8.10	-0.07	-4.15
	Long	183	3.17	1.97	3.2%	-2.49	0.78	-1.17
	McIntosh	191	159.34	99.01	94.1%	-7.97	0.85	-3.48
	Wayne	305	2.28	1.42	1.3%	-6.10	-2.10	-3.93
		Total	1185.23	736.50		Average length of road segments: 200 m		

Table 5.31 shows that all the counties analyzed have roads affected by this storm. Approximately 1185 kilometers (737 miles) of road are affected by this storm. Wayne, Long, and Brantley County roads have the smallest section of roads affected by this storm. The maximum level of water above the roads is about 8.9 meters (29.2ft) and the minimum level is 0.9 meters (2.95ft) under the road elevation. In all the segments of the roads affected by the storm surge, the average surge levels are above the road and higher than 1 meter (3.28ft) above the road. Table 5.31 also shows that Brantley, Liberty, Long, and Wayne County road segments affected by this storm are all under the surge. Glynn, Camden, Chatham, and McIntosh Counties have highest percent of road under surge: 92.6%, 98.1%, 94.4%, and 94.1%, respectively.

- Interstates, Airports, Ports, and Railroads

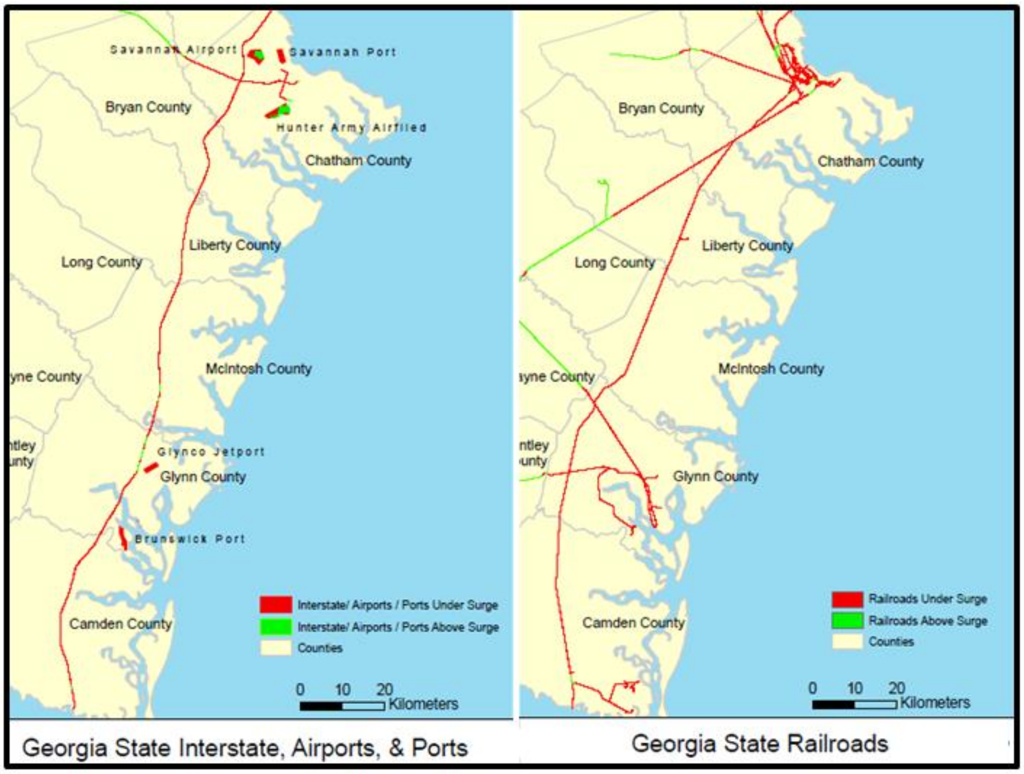


Figure 5.24: WNW525i4 Georgia State Interstates, Airports, Ports, and Railroads

From Figure 5.24 it can be observed that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. Also, it can be observed that the Savannah Airport is affected by this storm. Its polygon has a large area under surge, therefore large sections of the runway, terminals, access roads, and other infrastructures are considered to be affected by the storm. Hunter Army Airfield is affected by the storm. Because the red section in the airport polygon cover a large area and it is near the center of the polygon, the lower sections and other sections of the runway, access roads, buildings, and other infrastructures are considered to be affected. Glynco Jetport ground elevation is completely under the surge, therefore terminals and runways are subjected to the surge. See appendix B (B-34 & B-35) for a full view of the maps.

Table 5.32: Length of Interstate under Surge, WNW525i4

Storm	Interstate Name	Length of Interstate Under Surge		% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
		(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 25 mph; High tide	16	31.00	19.26	54.2%	-6.96	0.14	-3.07
	516	8.87	5.51	82.3%	-5.65	0.92	-2.55
	95	168.15	104.48	93.4%	-8.40	1.00	-4.09
	Total	208.02	129.25		Average length of road segments: 100 m		

Table 5.32 shows that 208 kilometers (129 miles) of interstate roads are affected by this storm surge. The maximum level of water above the interstate is about 8.40 meters (27.6ft), found on Interstate 95. The minimum level is 1 meters (3.28ft) under the interstate road elevation. Also, Table 5.32 shows that for all the segments of interstate roads affected by the storm surge the average surge levels are greater than 2.5 meters (8.2ft) above the roads. Interstates 95 and 516 have the highest percent of road under surge: 93.4% and 82.3%, respectively.

Table 5.33: Length of Railroads under Surge, WNW525i4

Storm	County	County Code	Length of Railroad Under Surge		% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m		
			(Km)	(miles)		Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 25 mph; High tide	Brantley	25	1.19	0.74	none	-4.10	0.90	-2.10
	Bryan	29	28.48	17.69	46.0%	-7.47	0.24	-4.19
	Camden	39	84.64	52.60	96.1%	-8.80	0.90	-3.36
	Chatham	51	275.37	171.11	95.1%	-8.25	0.94	-4.12
	Glynn	127	142.20	88.36	100.0%	-8.60	0.81	-4.87
	Liberty	179	47.70	29.64	69.8%	-7.75	-2.02	-4.37
	Long	183	1.69	1.05	7.8%	-1.29	0.85	-0.04
	McIntosh	191	31.07	19.31	100.0%	-7.99	-2.07	-4.17
	Wayne	305	1.66	1.03	1.1%	-5.10	-4.10	-4.77
		Total	614.00	381.52		Average length of railroad segments: 100 m		

Approximately 641 kilometers (381 miles) of railroad along the 9 counties analyzed are affected by this storm. Wayne and Brantley Counties have the smallest section of railroads affected by this storm. The maximum level of water above the railroads is about 8.8 meters (28.9ft), found on Camden County. The minimum level is 0.94 meter (3.08ft) under the railroad elevation. Table 5.33 shows that Liberty, McIntosh, and Wayne Counties railroad segments affected by this storm are all under the surge levels. Also, this table shows that for all the track segments affected the average surge levels are above the railroad elevation. McIntosh and Glynn Counties have all its railroads under surge. After these two counties, Camden and Chatham have the highest percent of railroad under surge: 96.1%, and 95.1%, respectively.

5.3.4 Hypothetical Storm: WNW Category 5, Forward Speed 35 mph or 56.32 km/hr, and High Tide

(WNW535i4)

- State Roads

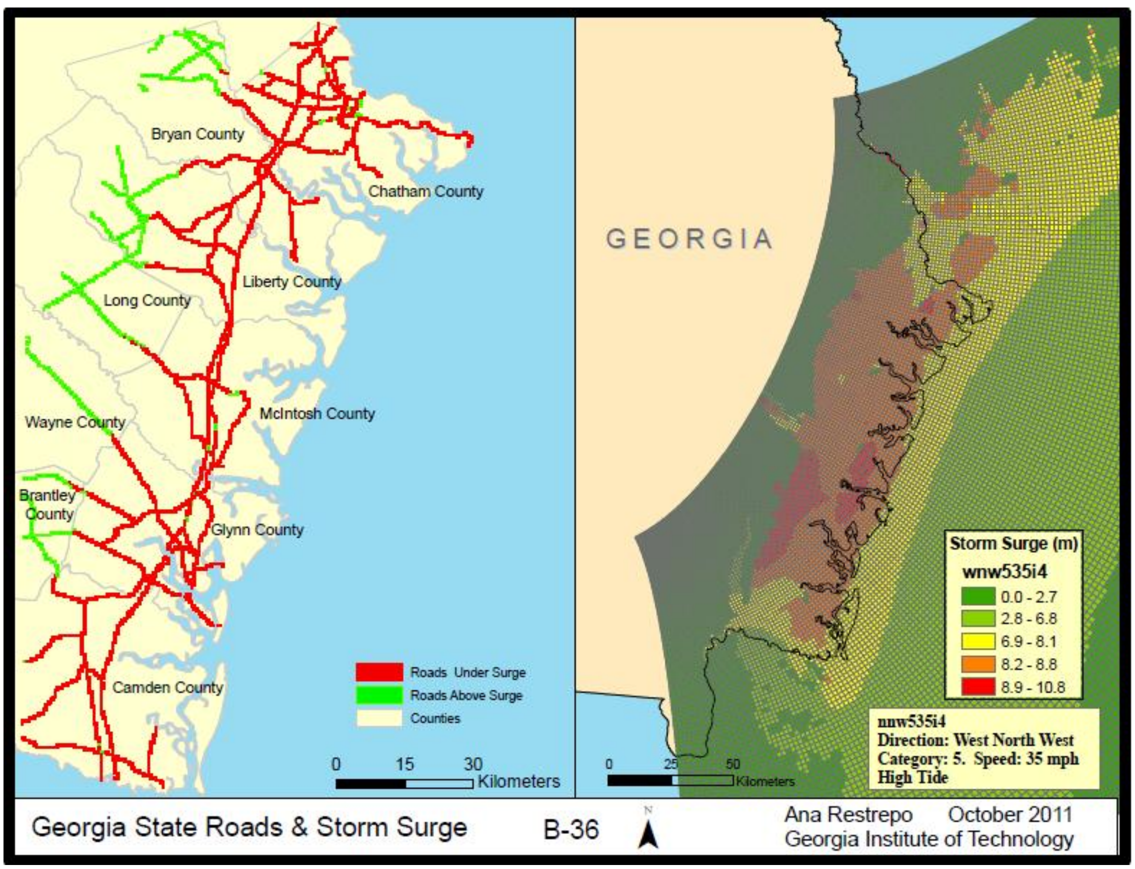


Figure 5.25 WNW535i4 Georgia State Roads & Storm Surge (see appendix B-36)

Table 5.34: Length of State Roads under Surge, WNW535i4

Storm	County	County Code	Length of Road Under Surge (Include Interstate) (Km)	(miles)	% of Road Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m: Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 35 mph; High tide	Brantley	25	3.18	1.98	2.1%	-5.70	-2.70	-3.98
	Bryan	29	121.61	75.57	55.1%	-8.50	-0.42	-4.33
	Camden	39	245.88	152.79	99.4%	-8.70	1.00	-3.34
	Chatham	51	315.25	195.90	95.0%	-8.50	0.91	-3.73
	Glynn	127	225.10	139.88	98.7%	-9.00	0.74	-4.99
	Liberty	179	129.57	80.52	57.1%	-8.10	0.03	-4.15
	Long	183	3.17	1.97	3.2%	-2.79	0.78	-1.44
	McIntosh	191	166.33	103.36	98.2%	-8.47	0.35	-3.73
	Wayne	305	2.28	1.42	1.3%	-6.60	-2.50	-4.33
		Total	1212.37	753.37		Average length of road segments: 200 m		

Table 5.34 shows that all the counties analyzed have roads affected by this storm. Approximately 1212 kilometers (753 miles) out of 1849 kilometers (1149miles) of road analyzed are affected by this storm. Camden, Glynn, and McIntosh Counties have all their roads under surge with the exception of very small segments of road. The counties having the highest percent of roads under surge are: Camden 99.4%, Glynn 98.7%, and McIntosh 98.2%. Wayne, Long, and Brantley County roads have the smallest section of roads affected by this storm. The maximum level of water above the roads is about 9 meters (29.52ft) and the minimum level is 1 meter (3.28ft) under the road elevation. In all the segments of the roads affected by the storm surge, the average surge levels higher than 1.4 meters (4.6ft) above the road. Table 5.34 also shows that Brantley, Bryan, and Wayne County road segments affected by this storm are all under the surge.

• Interstates, Airports, Ports, and Railroads

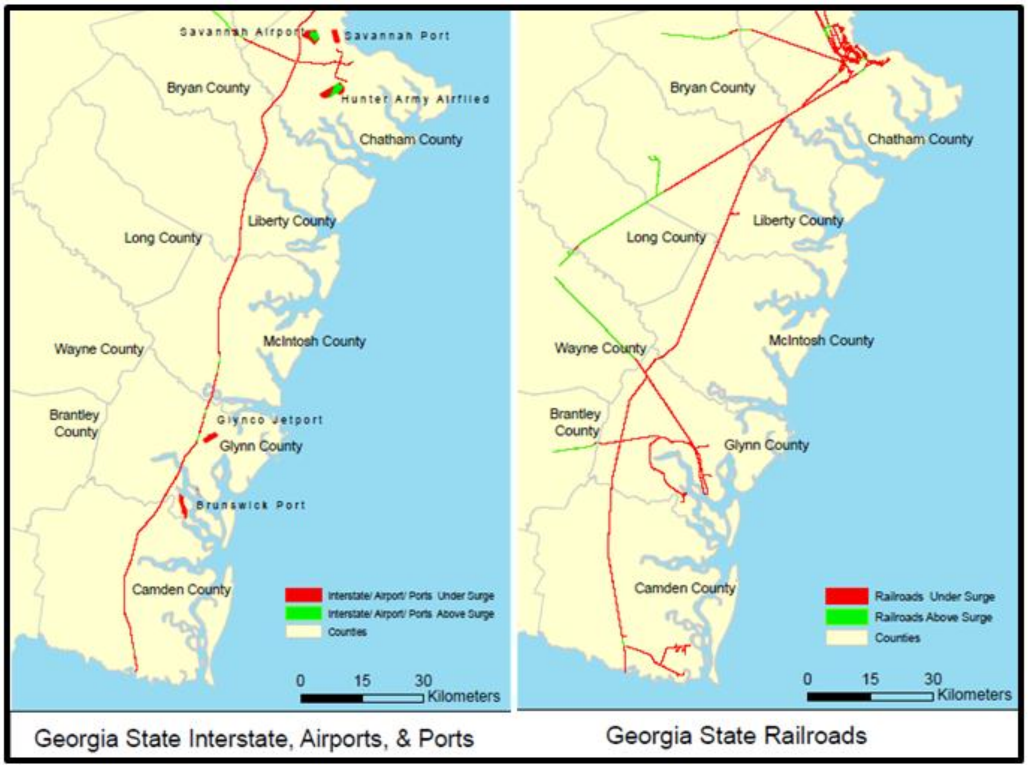


Figure 5.26: WNW535i4 Georgia State Interstates, Airports, Ports, and Railroads

From Figure 5.26 it can be observed that the areas assigned to the Savannah and Brunswick Ports are completely under the surge. Also, it can be observed that Hunter Army Airfield and the Savannah Airport are affected by this storm. Their polygons have a large area under surge, therefore large sections of the runway, terminals, access roads, and other infrastructures are considered to be affected by the storm. Glynco Jetport ground elevation is completely under the surge, therefore terminals and runways are affected by the surge. See appendix B (B-37 & B-38) for a full view of the maps.

Table 5.35: Length of Interstate under Surge, WNW533i4

Storm	Interstate Name	Length of Interstate Under Surge (Km)	Length of Interstate Under Surge (miles)	% of Interstate Under Surge	Road Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m: Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 35 mph; High tide	16	30.19	18.76	52.8%	-7.06	-0.06	-3.19
	516	9.40	5.84	87.2%	-5.75	0.92	-2.46
	95	171.61	106.63	95.3%	-8.70	1.00	-4.10
	Total	211.20	131.23		Average length of road segments: 100 m		

Approximately 211 kilometers (131 miles) out of 248 kilometers (147miles) of interstate roads analyzed are affected by this storm surge. The maximum level of water above the interstate is about 8.70 meters (28.5ft), found on Interstate 95. The minimum level is 1 meter (3.28ft) under the interstate road elevation. Also, Table 5.35 shows that for all the segments of interstate roads affected by the storm surge the average surge levels are greater than 2.4 meters (7.87ft) above the roads. Interstates 95 and 516 have the highest percent of road under surge: 95.3% and 87.2%, respectively.

Table 5.36: Length of Railroads under Surge, WNW535i4

Storm	County	County Code	Length of Railroad Under Surge (Km)	Length of Railroad Under Surge (miles)	% of Railroad Under Surge	Railroad Elevation - Surge Elevation = (-) all values under surge; (+) values above surge from 0 m to 1 m: Maximum Level (m)	Minimum Level (m)	Mean (m)
WNW Category 5; Speed: 35 mph; High tide	Brantley	25	1.19	0.74	1.6%	-4.20	0.80	-2.20
	Bryan	29	27.49	17.08	44.4%	-7.57	0.24	-4.28
	Camden	39	85.82	53.33	97.5%	-9.10	1.00	-3.55
	Chatham	51	275.61	171.26	95.1%	-8.25	0.89	-4.18
	Glynn	127	142.20	88.36	100.6%	-8.70	0.51	-5.11
	Liberty	179	47.70	29.64	69.8%	-7.85	-1.92	-4.42
	Long	183	1.69	1.05	5.4%	-1.29	0.67	-0.10
	McIntosh	191	31.07	19.31	100.0%	-8.29	-2.27	-4.35
	Wayne	305	1.66	1.03	1.1%	-5.50	-4.50	-5.23
		Total	614.44	381.79		Average length of railroad segments: 100 m		

Approximately 641 km (381 miles) of railroad along the 9 counties analyzed are affected by this storm. Wayne and Brantley Counties have the smallest section of railroads affected by this storm. The maximum level of water above the railroads is about 9.1 meters (29.9ft), found on Camden County. The minimum level is 1meter

(3.28ft) under the road elevation. Table 5.36 shows that Liberty, McIntosh, and Wayne Counties railroad segments affected by this storm are all under the surge levels. Also, this table shows that for all the rail segments affected by the storm surge the average surge levels are above the track elevations. McIntosh and Glynn County have all their railroads under surge. After these two counties, Camden and Chatham Counties have the highest percent of railroad under surge: 97.5%, and 95.1%, respectively.

5.4 West North-West Category 1 and 2

5.4.1 Hypothetical Storm: WNW Category 1, Forward Speed 35 mph or 56.32 km/hr, and High Tide

(WNW135i4)

- State Roads

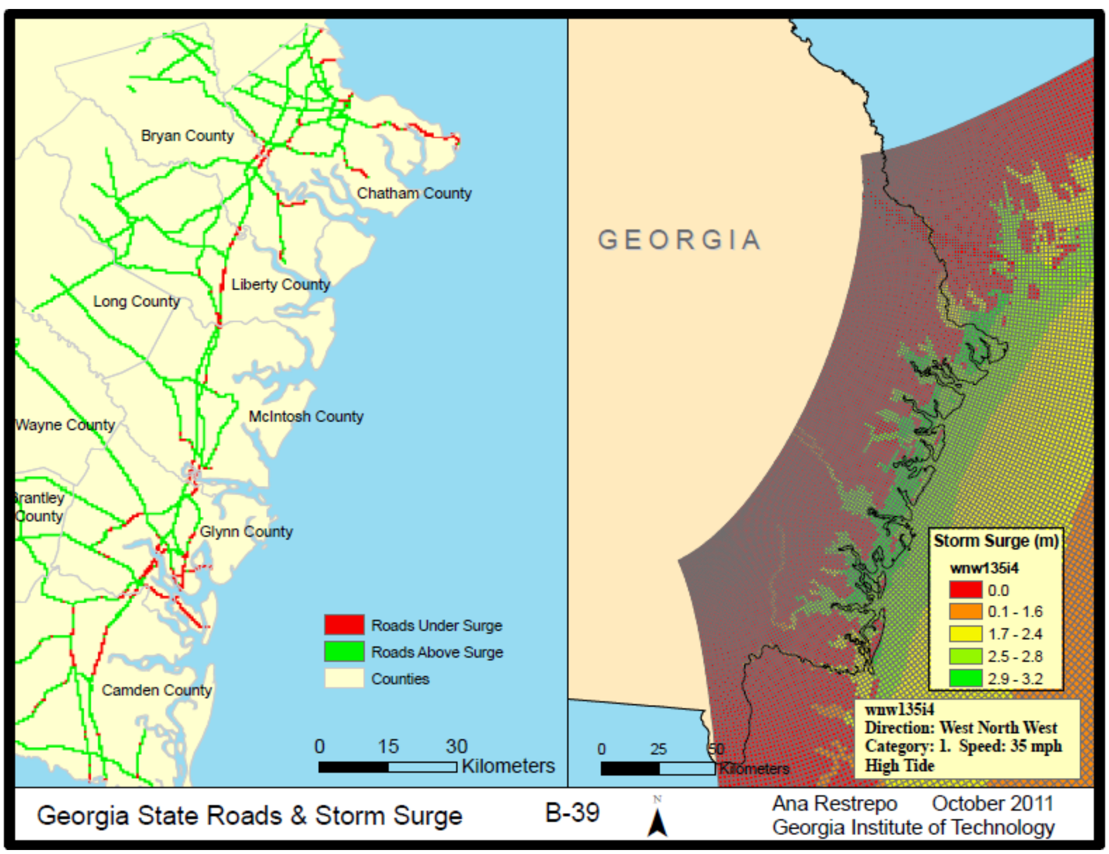


Figure 5.27: WNW135i4 Georgia State Roads & Storm Surge (see appendix B-39)

Figure 5.27 illustrates that the storm does not have a major impact on roads. Brantley, Wayne, and Long Counties roads are not affected by the storm. Because many roads in Glynn County are close to the shore, those are the most affected by the storm. Figure 5.27 (left) shows that the storm surge covers a very small area of each of the counties along the coast. Therefore, a low amount of road segments are affected by the storm. However, because the highest elevation of the storm surge is 3.2 meters (10.5ft), the roads near the shore that have low elevation can be a few meters under surge (less than 3.2 meters).

- Interstates, Airports, Ports, and Railroads

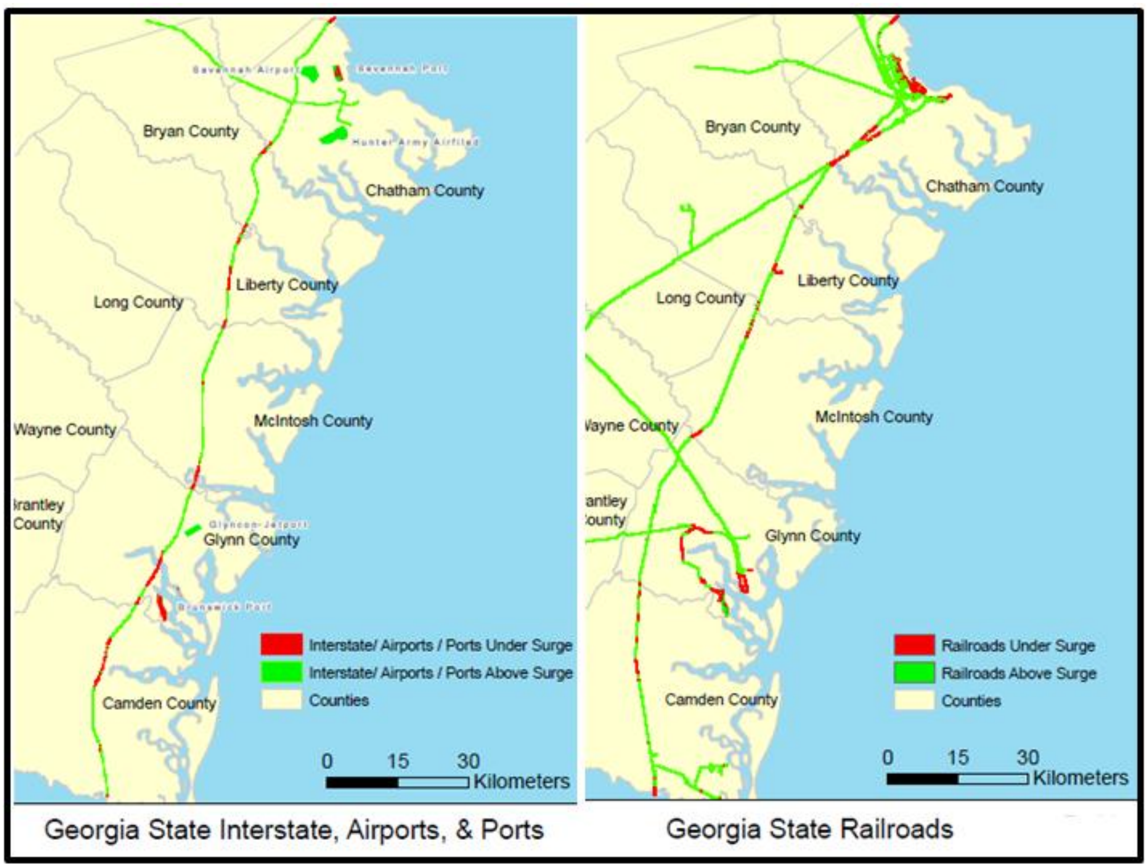


Figure 5.28: WNW135i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.28 shows that the Savannah Airport, Hunter Army Airfield, and Glynco Jetport are not affected by the storm. A large section of the area assigned to the Savannah Port is affected by the storm. Therefore, many facilities, access roads, and other infrastructures of this port are considered to be affected by the storm. Brunswick Port is completely under the surge elevation. Similar to the roads, Brantley, Wayne, and Long Counties railroads are not affected by the storm. For the counties along the coast, the storm surge does not have major impacts on the railroads. Only a small section of railroads are affected; especially in Glynn and Chatham Counties. See appendix B (B-40 & B-41) for a full view.

5.4.2 Hypothetical Storm: WNW Category 2, Forward Speed 35 mph or 56.32 km/hr, and High Tide

(WNW235i4)

- State Roads

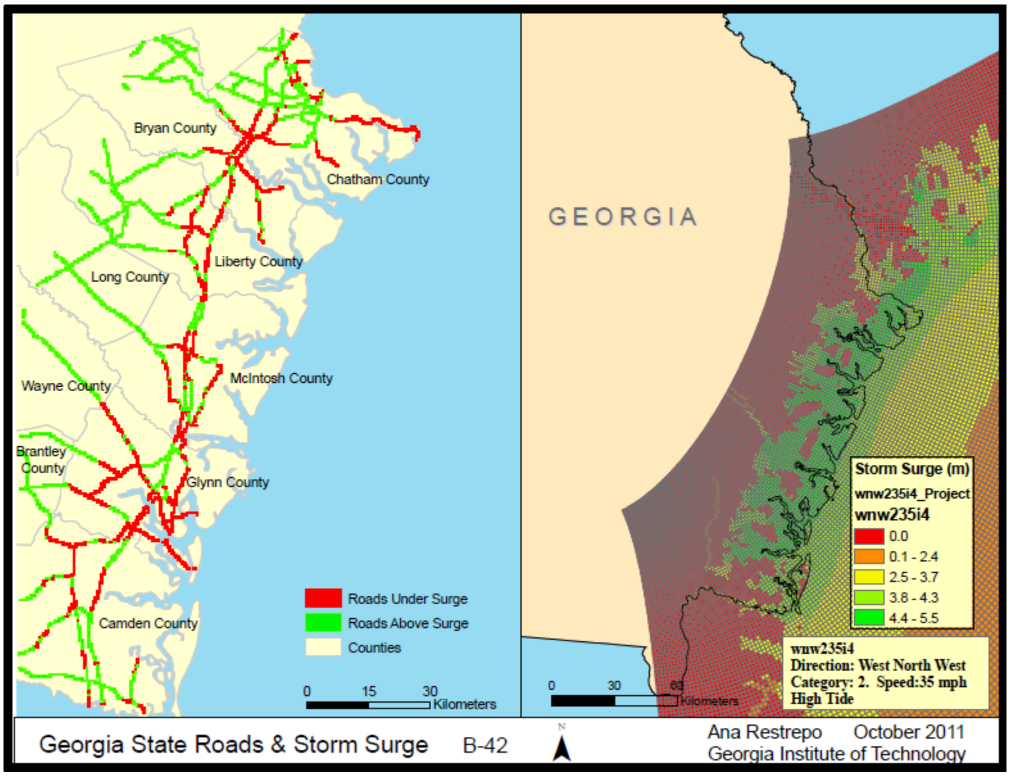


Figure 5.29: WNW235i4 Georgia State Roads & Storm Surge

Figure 5.29 shows that Brantley, Wayne, and Long Counties roads are not affected by the storm. The other 6 counties have many segments of roads affected by the storm. From figure 5.29 (right) shows that the storm surge covers a larger area than the category 1 storm. When comparing this storm with storm West North-West Category 3, speed 05mph (see appendix B-3), it can be observed that the two storms have very similar impacts on roads. Even though these storms are very similar, the Category 3 storm still has more impact on roads.

- Interstates, Airports, Ports, and Railroads

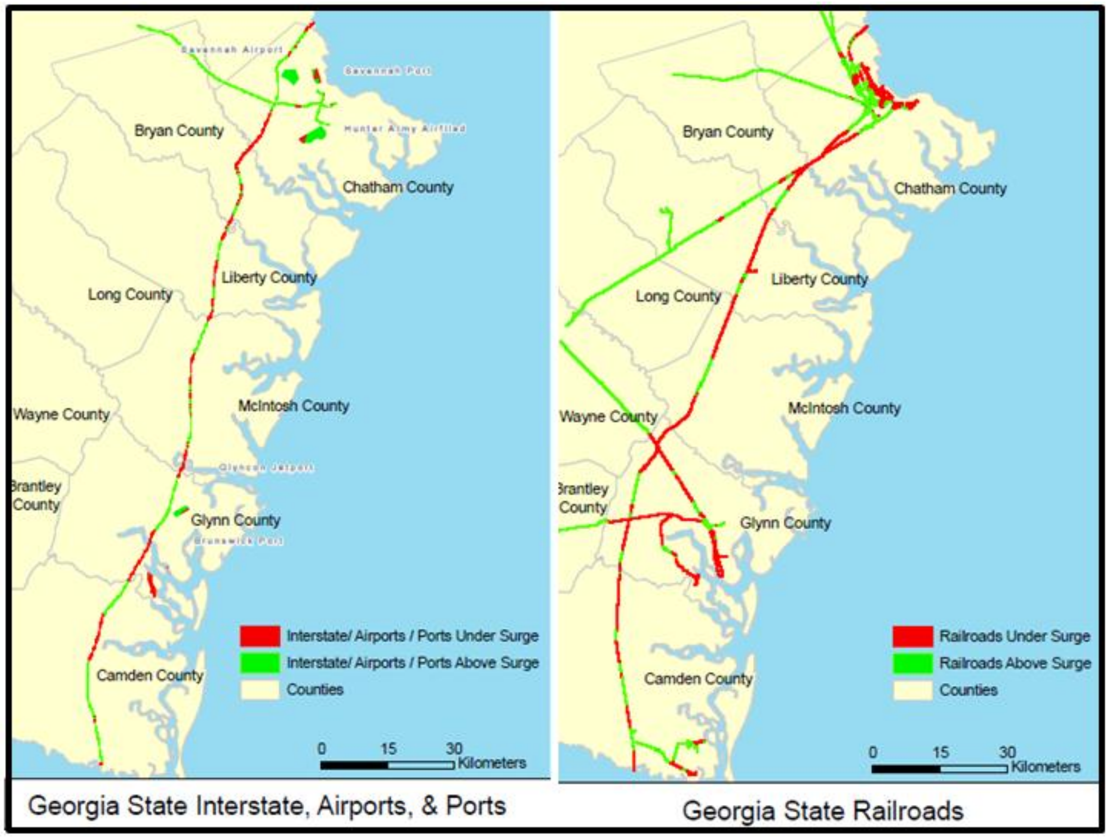


Figure 5.30: WNW235i4 Georgia State Interstates, Airports, Ports, and Railroads

Figure 5.2 shows that the Savannah Airport is not affected by the storm. A small section of the area assigned to the Hunter Army Airfield and Glynco Jetport is affected by the storm. Because these sections are in the laterals of the polygons, the terminals and runways of the airports are considered to be out of the affected area. Figure 5.30 shows that Brunswick Port is completely under surge and a large area of the Savannah Port assigned polygon is affected by the storm. Therefore, many facilities, access roads, and other infrastructures of this port are considered to be affected by the storm. See appendix B (B-43 & B-44) for a full view of the maps. Similar to the roads, Brantley, Wayne, and Long County railroads are not affected by the storm and the amount of railroads affected by the storm of the other counties is very similar to the amount of railroads affected by

WNW305i4 (Category 3, 05mph) storm.

CHAPTER: 6

SUMMARY OF RESULTS AND DISCUSSION

This chapter provides a summary of the results given in chapter 5, summarized by storm. For each storm, information of total length and percentage of roads, Railroads, and interstates under surge is provided. The nine counties analyzed are divided into two groups to provide the length and percentage information for roads and Railroads. The groups are those: counties along the coast and those not along the coast. Counties along the coast include: Bryan, Camden, Chatham, Glynn, Liberty, and McIntosh Counties. Counties not along the coast include: Brantley, Long, and Wayne Counties. Also, from the nine counties analyzed, the maximum and average level of surge above the roads, railroads, and interstates are provided. In addition, this chapter contains a discussion of the results of chapter 5. Note that negative values for surge elevation means that surge level is above the road, railroad, or interstate. For the charts, the average surge level was converted to a positive value for better understanding.

6.1 State Roads

Table 6.1: Summary of Roads Affected by the 12 Hypothetical Storms Analyzed

Storm DDD100i4 Direction Category Speed mph i4: High Tide	Length of Roads Under Surge Counties Along the Coast		Length of Roads Under Surge Counties Not Along the Coast		Level of Surge Above the Roads (-) (For all Counties Analyzed)		
	Total (Km)	total % of Roads Under Surge	Total (Km)	total % of Roads Under Surge	Maximun Level		Average Level
					(m)	County	(m)
WNW305i4	647.89	45.49%	0.30	0.07%	-4.90	Bryan & Camden	-1.35
WNW315i4	792.51	55.64%	1.25	0.30%	-5.60	Bryan	-1.66
WNW325i4	900.79	63.25%	2.66	0.63%	-6.10	Bryan,Chatham & Liberty	-1.70
WNW335i4	974.93	68.45%	3.28	0.77%	-6.20	Bryan & Glynn	-1.68
WNW405i4	1021.59	71.73%	2.66	0.63%	-6.00	Candem	-1.61
WNW415i4	1099.89	77.22%	5.45	4.05%	-6.90	Bryan&Chatham	-1.91
WNW425i5	1138.19	79.91%	7.73	1.82%	-7.30	Bryan, Camden &Chatham	-2.47
WNW435i5	1145.47	80.42%	8.23	1.94%	-7.50	Glynn	-2.61
WNW505i4	1123.71	78.90%	6.65	1.57%	-7.00	Bryan, Camden &Chatham	-2.15
WNW515i4	1151.66	80.86%	8.63	2.03%	-8.00	Bryan & Camden	-3.00
WNW525i4	1185.23	83.22%	8.63	2.03%	-8.90	Glynn	-3.61
WNW535i4	1212.37	85.12%	8.63	2.03%	-9.00	Glynn	-3.78

From Table 6.1 it can be observed that generally the length of roads under surge increase as the speed and categories of the storm increase. However, there are some cases where the length of roads under surge decreases. For example, storm West North-West, Category 5, Speed 05 mph (WNW505i4) has a small reduction in the total length of roads under surge when it is compared with the storms of Category 4: WNW425i3 and WNW 435i4. The SLOSH storm model generates a grid for each hypothetical storm. Each cell of the grid provides the storm surge elevation in that particular location. Every storm generates some spots in different locations along the area affected by the storm that do not have storm surge elevation (dry sections). For storm WNW505i4, there are several “dry” spots that coincide with some of the road segments that are not in the Category 4 storms. (See this storm grid and elevation on appendix B-27). These “dry” spots were not found in the other Category 5 storms for the counties along the coast.

The total percentage of roads under surge increases from 45.49% to 85.12% as the storm intensity increases. Storms with speeds of 05 and 15 mph, and speeds of 25 and 35 mph generate very similar storm surge elevations and, as a result, these generate similar percentage of roads under surge. As the intensity of the storms increase, the percentage of roads under surge also increases for the counties that are not along the coast. When the storm intensity increases, the storm surge has the potential to reach locations farther inland. In other words, the area of inundation produced by the storm is larger as the storm intensity increases. The levels of inundation or levels of surge above the roads increase rapidly as the intensity of the storm increases. For example, Category 3 storms have a maximum level of surge above the road, which varies from 4.90 meters (16.1ft) to 6.20 meters (20.3ft), and for Category 5 storms, the maximum levels go up to 9 meters (29.5ft). Generally, Bryan and Camden Counties present the highest inundation levels found in the analysis. Also, Glynn and Chatham Counties have some of the highest levels among the 12 storms analyzed.

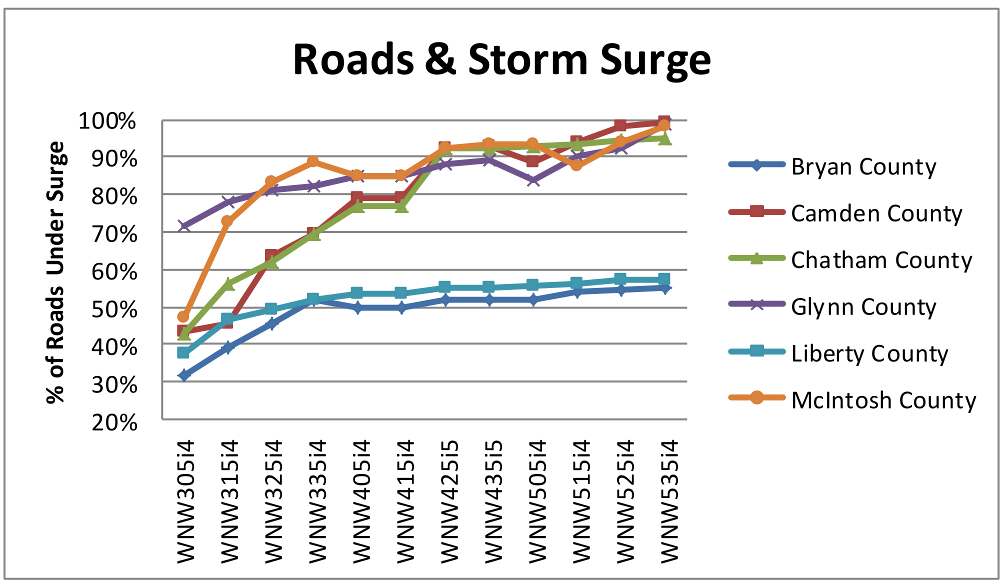


Figure 6.1: Chart- Storm Surge vs. % of Roads under Surge

Figure 6.1 illustrates the percentage of roads under surge vs storm surge for the six counties along the coast. It can be observed that the Glynn County percentage of roads under surge starts (WNW305i4) with the highest percent out of all the counties along the coast. From chapter 5, it can be observed that the Glynn County percent of roads under surge varies in Category 3 from 71.8% to 82%, Category 4 from 84.7% to 89.2% , and Category 5 storms from 83.7 % to 98.7 %. Even though Camden County starts with a low percentage of roads under surge for Category 3 (43.2%), this percentage increases significantly from Category 4 to 5 (78.9% to 99.4%). A similar case is observed for Chatham and McIntosh Counties, where the percentage of roads under the surge starts at 43% in Category 3 and goes up to 98.2% in Category 5. In Bryan and Liberty Counties, the percentage of road under surge does not exceed 60% percent of the roads. Even though these counties are along the coast, they have a larger inland area than the other counties; therefore, a large section of roads (inland roads) is not reached by the storm.

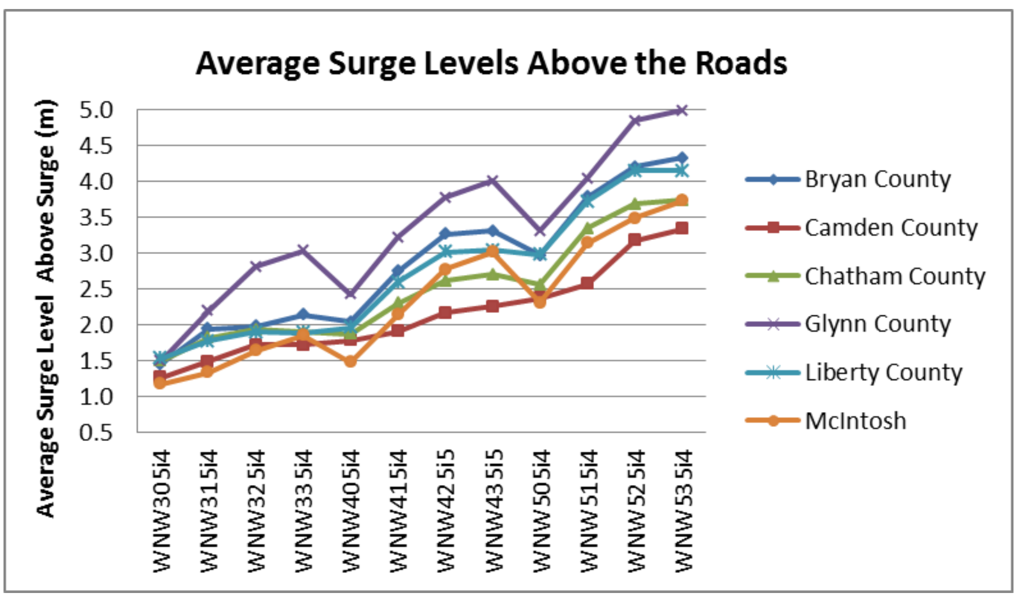


Figure 6.2: Chart- Storm Surge vs. Average Surge Levels Above the road

Figure 6.2 illustrates the average surge levels above the road vs storm surge for the six counties along the coast. The average levels are calculated with all the levels above the road and the levels under the road from zero to one meter. All average surge levels obtained were negative, therefore these levels are above the roads. The average surge levels above the roads for these 6 counties vary from 1.35 meters (4.43ft) in Category 3 to 3.78 meters (12.4ft) in Category 5 storms. Glynn County presents the highest average surge levels above the roads among the 12 storms analyzed. Even though many of the maximum surge levels are found in Camden County, the average levels are the lowest among the counties along the coast. Because levels from zero to one meter under the level of the roads are considered to be levels under surge or levels that affect the roads, the average levels can be reduced significantly when a county has many segments of road with surge elevation in this range. After Glynn County, Bryan County has the second highest average surge elevation. The order of average surge levels above the roads for the counties along the coast is (descending order): Glynn County, Bryan County, Liberty County, Chatham County, McIntosh County and Camden County.

6.2 Interstate Roads

Table 6.2: Summary Interstate Roads Affected by the 12 Hypothetical Storms Analyzed

Storm DDD100i4 Direction Category Speed mph i4: High Tide	Length of Interstate Roads Under Surge		Level of Surge Above the Interstate Roads (-)		
	Total (Km)	total % of Interstate Under Surge	Maximun Level		Average Level
			(m)	Interstate	(m)
WNW305i4	104.98	42.34%	-4.90	95	-0.89
WNW315i4	136.98	55.25%	-5.70	95	-1.18
WNW325i4	146.13	58.94%	-6.20	95	-1.42
WNW335i4	156.79	63.24%	-6.30	95	-1.41
WNW405i4	163.90	66.10%	-6.10	95	-1.64
WNW415i4	183.79	74.13%	-6.90	95	-2.05
WNW425i5	193.28	77.96%	-7.40	95	-2.37
WNW435i5	195.60	78.89%	-7.70	95	-2.43
WNW505i4	187.80	75.74%	-7.00	95	-2.39
WNW515i4	201.34	81.20%	-8.00	95	-2.94
WNW525i4	208.02	83.90%	-8.40	95	-3.24
WNW535i4	211.20	85.18%	-8.70	95	-3.25

The percentage of interstate roads under surge increases as the intensity of the storm increases (from category 3 to 5 and from 05 mph to 35 mph). The percentage of interstate roads under surge starts at 42.34% with Category 3 and goes up to 85.18 % with Category 5 storms. Because Interstate 95 goes along the coast, it has the highest percent of road under surge. For Category 3 storms, the percentage varies from 59.98% to 72%. For category 4, the percentage varies from 78.4% to 90% and it goes up to 95.3% with Category 5. Interstate 516, located in Chatham County, also has a high percentage of roads under surge. For example, in Category 5 storms, Interstate 516 has up to 87% of the road under the surge (See appendix A Interstate Result table). The maximum level of surge above the interstate roads for each of the 12 storms analyzed is found on Interstate 95. The maximum levels start at 4.90 meters (16.07ft) in Category 3 and increase to 8.70 (28.5ft) meters in category 5.

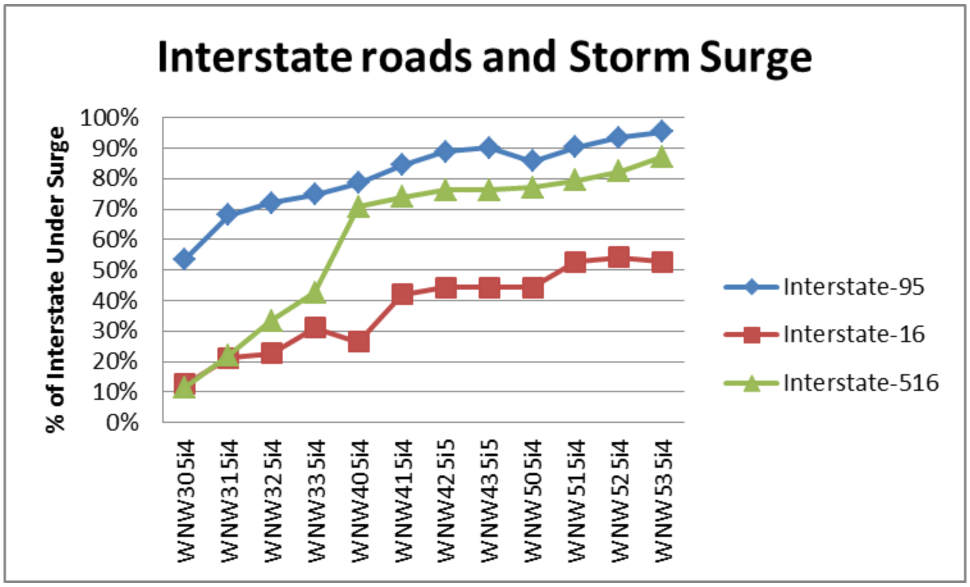


Figure 6.3: Chart- Storm Surge vs. % of Interstate Roads under Surge

From Figure 6.3 It can be observed that Interstate 95 has the highest percentage of roads under surge followed by Interstate 516 and Interstate 16. The percentage of roads under surge of Interstate 516 increases significantly from Category 3 to Category 4 storms. The percentage of roads under surge changes from 42.5% with a WNW335i4 storm to 70.8 % with a WNW405i4 storm. The percentage of roads under surge for Interstate 95 starts (WNW305i4) with the highest percent out of all the Interstates analyzed. Similar to the state roads mentioned in section 6.1, the percentage of Interstate 95 roads under surge has a small dip in the chart in the first storm of the Category 5 Storms (WNW505i4). This reduction is also observed in the first storm of the Category 4 storms (WNW405i4) but only for Interstate 516.

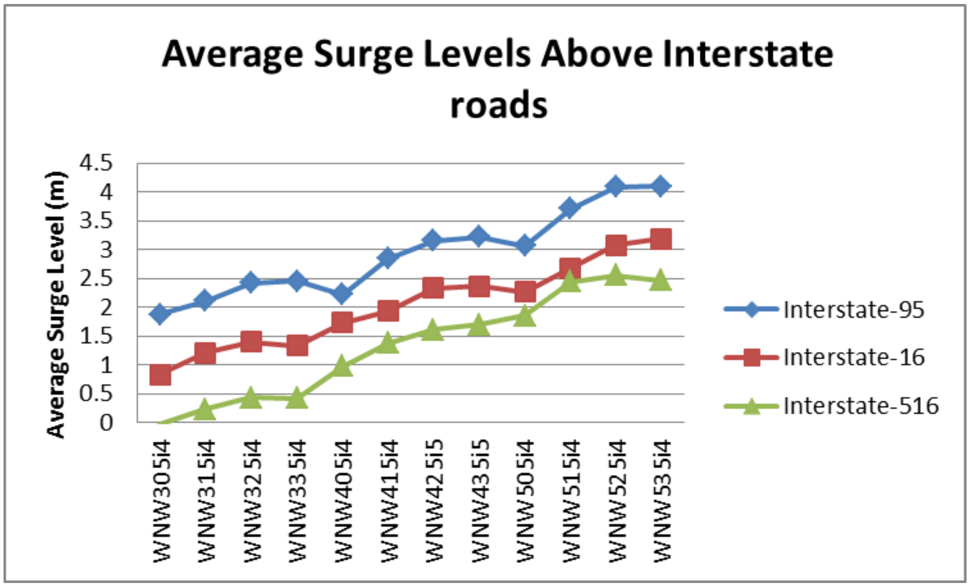


Figure 6.4: Chart- Storm Surge vs. Average Surge Levels Above the Interstate Roads

The average levels of surge above the interstate roads start at 0.98 meters (3.22ft) and increase to 3.25 meters (10.66ft) as the intensity of the storm increases. Interstate 95 has the highest average surge levels above the road starting at 1.88 meters (6.17ft) in Category 3 storms and going up to 4.10 meters (13.45ft) in Category 5 storms. Interstate 516 average surge levels start at the same elevation of the road with Category 3 storms and go up to 2.46m above the road with Category 5 storms. Figure 6.4 shows that the average surge elevation for Interstate 95 has a small reduction in storm WNW405i5 and storm WNW505i4. It is due to the “dry” spots on the storm surge grid generated by the SOLSH model (case explained in section 6.1)

6.3 Airports and Ports

The maps of airports and ports for each of the storms analyzed (see chapter5) shows that Brunswick Port is completely under surge from the first storm of Category 3 to the last storm in Category 5. From the maps made for category 1 and 2 (speed 35mph) storms, it can be observed that Brunswick Port is also completely under surge. (See appendix B-40 and 43). Therefore, it can be stated that any category storm with direction West North-West would affect Brunswick port.

For Category 1 and 2 storms, a large section of the Savannah Port is affected by the storm surge. From the first Category 3 storms (WNW305i4), the Savannah Port is completely affected by the storm surge. Because the Savannah and Brunswick ports are located on the shore, the ports have very low ground elevation and any storm will affect their terminals, roads access of these ports, and other infrastructures. Because Glynco Jetport has a low ground elevation, storms from Category 3 (starting at 15 mph) storms with a speed of 15 mph to the last storm of Category 5 storms affects this airport. The Hunter Army Airfield is not affected by a Category 1 WNW135i4 storm and only a very small section in the proximities of the airport is affected by a Category 2 WNW235i4 storm. Some sections of the Hunter Army Airfield are affected by Category 3 storms with speed of 15 mph, 25 mph and 35 mph. Because the sections affected are near the center of the Hunter Army Airfield polygon assigned area, some sections of infrastructures or terminals are considered to be affected. For Category 4 storms and the first storm of Category 5 (WNW50i54), the sections affected cover a larger area of the Hunter Army Airfield; therefore the lower sections of the runway or the ends, road access, and other infrastructures located in this area are considered to be affected. For the other 3 storms of Category 5, the sections affected by the storms cover a significant area of the Hunter Army Airfield, especially with WNW535i4 storm. For storm WNW535i4, large sections of the runway, terminals, access roads, and other infrastructures are considered to be affected. Savannah International Airport is not affected by the storms of

Category 1, 2, and the first storm of Category 3 (WNW305i4). With the other storms of Category 3 and the first storm of Category 4 (WNW405i4), some sections of the polygon assigned for the Savannah Airport are affected by the storm. These sections are located in the laterals of the polygon but they tend to move to the center of the polygon; therefore lower sections or the ends of the runway are considered to be affected by the storm as well as some access roads and buildings. The Savannah Airport experiences a significant impact with storm surges from Category 4 storms (speeds 15mph to 35pmh) to Category 5 storms. Large areas of the Savannah Airport are under surge with these storms, therefore large sections of the runway, terminals, access roads, and other infrastructures are considered to be affected.

6.4 Railroads

Table 6.3: Summary Railroads Affected by the 12 Hypothetical Storms Analyzed

Storm DDD100i4 Direction Category Speed mph i4: High Tide	Length of Railroads Under Surge Counties along the Coast		Length of Railroads Under Surge Counties Not along the Coast		Level of Surge Above the Railroads (-) (For all Counties Analyzed)		
	Total (Km)	total % of Interstate Under Surge	Total (Km)	total % of Interstate Under Surge	Maximun Level		Average Level
					(m)	County	(m)
WNW305i4	372.51	54.75%	0.36	0.49%	-4.90	Camden	-1.20
WNW315i4	457.05	67.17%	1.66	2.27%	-5.45	Chatham	-1.55
WNW325i4	474.37	69.71%	1.66	2.27%	-6.00	Glynn	-1.92
WNW335i4	492.73	72.41%	1.66	2.27%	-6.20	Glynn	-1.98
WNW405i4	548.90	80.67%	1.66	2.27%	-5.90	Camden & Chatham	-1.83
WNW415i4	563.61	82.83%	1.66	2.27%	-6.60	Camden	-2.66
WNW425i5	596.27	87.63%	1.66	2.27%	-7.40	Camden	-3.11
WNW435i5	597.93	87.87%	1.66	2.27%	-7.60	Camden	-3.24
WNW505i4	586.33	86.17%	1.66	2.27%	-7.00	Camden	-2.83
WNW515i4	600.60	88.27%	1.66	2.27%	-7.90	Camden	-3.69
WNW525i4	609.46	89.57%	4.55	6.19%	-8.80	Camden	-3.55
WNW535i4	609.89	89.63%	4.55	6.19%	-9.10	Camden	-3.71

Railroad analysis outputs have many similarities with road outputs discussed in section 6.1. The percentage of railroads under the surge increases as the intensity of the storm increases. For the counties along the coast, 54.75 % of the railroads are under surge when subjected to a WNW305i4 storm and 89.63 % of the railroads are under surge when subjected to a WNW535i4 storm. All the storms from Category 4 and 5 affected more than 80% of the railroads located in the counties along the coast. The levels of surge above the railroads elevation increase rapidly as the intensity of the storm increases. To illustrate, maximum levels of surge above the railroad vary from 4.90 meters (16.1ft) to 6.20 meters (20.3ft) when railroads are subjected to Category 3 storms and up to 9.10 meters (29.85ft) when those are subjected to Category 5 storms. The average levels of surge above the railroads vary from 1.20 (3.93ft) meters in Category 3 storms to 3.71 meters (12.17ft) in Category 5.

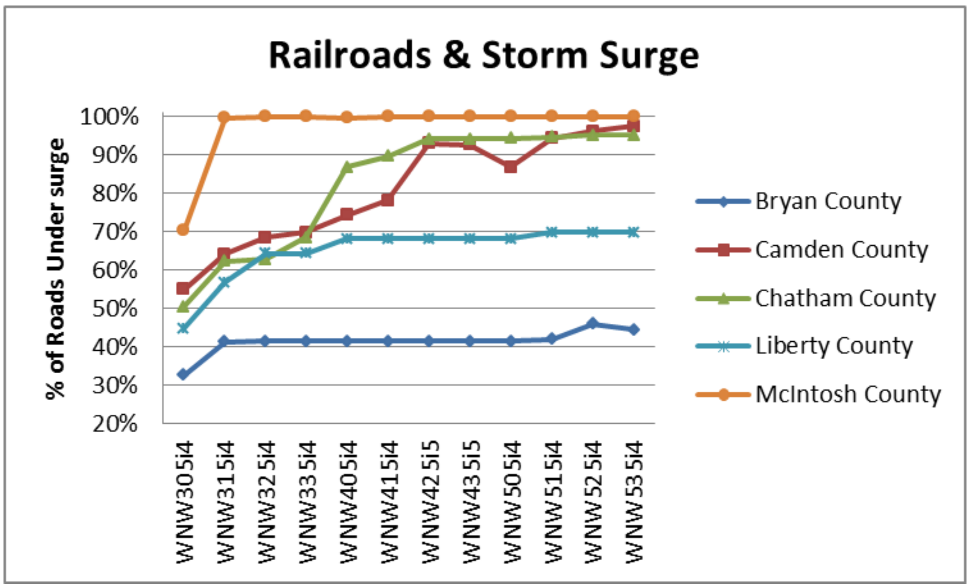


Figure 6.5: Chart- Storm Surge vs. % of Railroads under Surge

Figure 6.4 shows that McIntosh County has the highest percentage of railroads under surge for each of the storms. Its percentage starts at 70.4% with the first storm of the Category 3 storms (WNW305i4) and increases to 100% in the second storm of Category 3 (WNW315i4) and continues at 100% until the last of the Category 5 Storms. Bryan County has the lowest percentage of railroads under surge among the other counties along to coast. It starts at the lowest percent (32.6%) and increases to 44.4 %. With analysis of the Category 5 storms, Chatham and Camden Counties have almost 100% of their railroads under surge. Liberty County has more than 50% of its railroads under surge starting with WNW315i4 storm. However, its highest length of railroads under surge does not exceed 70%.

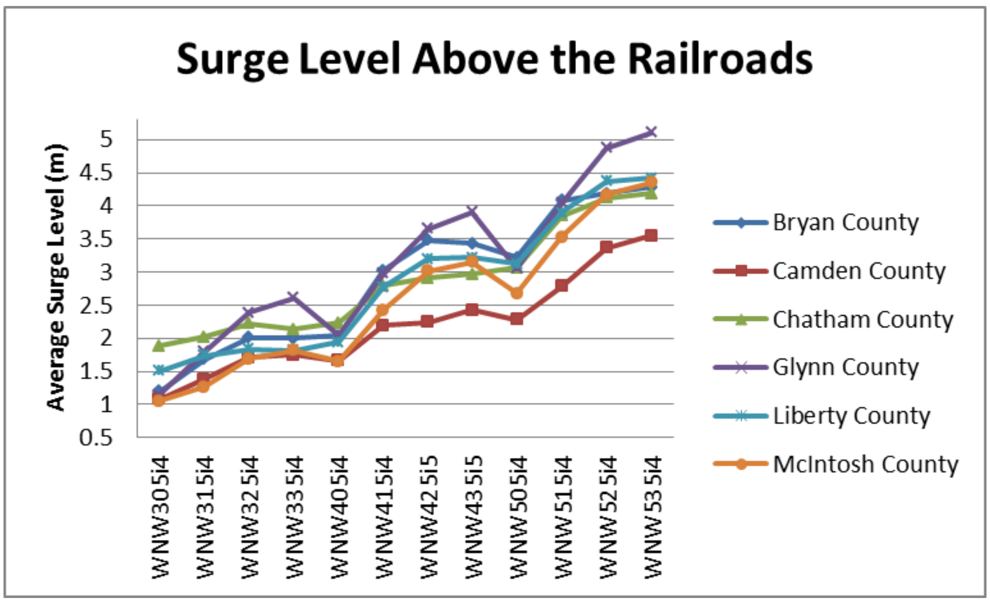


Figure 6.6: Chart- Storm Surge vs. Average Surge Levels above the Railroads

This chart illustrates the average surge levels above the railroad vs storm surge for the six counties along the coast. Similar to the state roads, the average surge levels of the railroads are calculated with the levels above the railroad and the levels under the railroad from zero to one meter. All the average surge levels obtained were negative therefore these levels are above the railroads. The average surge levels above the railroads for these 6 counties varies from 1.20 meters (3.93ft) in Category 3 storms to 3.71 meters (12.1ft) in Category 5 storms. Glynn County presents the highest average surge levels above the railroads among the 12 storms analyzed. However, the average level decreases with storm WNW40i5 and storm WNW50i5. This decrease in the average surge elevation is seen for all the railroads of the counties along the coast. For all the counties analyzed, the average surge level tends to increase as the intensity of the storm increases. Similar to the state roads in Camden County, the railroads have the lowest average surge levels among the counties along the coast. Bryan, Liberty, and Chatham counties have similar average surge levels above the railroads.

CHAPTER 7

CONCLUSIONS

The objective of this thesis was to provide knowledge and awareness of the transportation system in the Georgia coastal is that are at risk of suffering the impacts of a hurricane storm surge. The literature review provided background on storm surge and the major impacts that can affect the transportation system along the Georgia coast. The result of storm surge analysis demonstrated that a large portion of the Georgia coast transportation system is at risk. Knowing how damaging a storm surge can be on the transportation system, the infrastructure assets that are at risk, and knowing that this risk may increase with global warming leads to assessments and other studies that can be undertaken to mitigate the impacts of a hurricane event on the transportation system.

This study shows that Category 3, 4, and 5 hurricanes can result in significant impacts on the transportation system along the Georgia coast, where impact is defined as being under water. The results also illustrate that Category 2 storms may be just as damaging as the least intense Category 3 storms. For Category 3 storms, 40% to 69% of the roads, interstates, and railroads of the counties along the coast will be affected. For Category 4 and 5 storms, 65% to 80% and 75% to 90 % (respectively) of the roads, interstates, and railroads of the counties along the coast will be affected. There are no major impacts on the transportation assets when subjected to Category 1 storms, however, some small sections of the roads, interstates, and railroads will be minimally affected. It is important to emphasize that the Savannah and Brunswick ports would be affected by any hurricane category (with direction: West North-West). In this study the surge elevations of all the possible directions of a hurricane event in the Georgia coastal area were analyzed and the direction with the highest surge elevation was selected for the study (West North-West). Even though each direction generates different surge elevations in different locations, the analysis of the directions North West, North-North West, West North-West, and West demonstrate that these directions generate similar surge elevations. Similar percentage of the transportation systems affected by the storms with direction West North –West can occur with the other 3 directions.

The results provided in chapter 5 and 6 are an approximation of what could happen if the roads, railroads, airports, and ports of the Georgia coast are subjected to a hurricane event with certain characteristics. Depending on the characteristics of the storm and the amount of rainfall during the event, the results can vary having less or more severe impacts on the transportation assets than the impacts shown in chapter 5 and 6. For this study the amount of rainfall was not in the inundation calculations of the transportations system on the Georgia coast. Hurricane events can produce severe rainfalls that increase the possibility of flooding events. Adding rainfall amounts to the analysis would vary the levels of inundation already obtained and some sections of roads, railroads, interests, airports, and ports that were not considered to be affected by the storm may be affected. The use of other storm surge models that estimate rainfall amount is suggested for future analysis. Also, acquiring ground elevation data with higher resolution than 1/3 arc-second (10 meters) would improve the accuracy of the results. Applying these and other improvements to further studies would help to determine more accurate levels of inundation.

This thesis provides a broad overlook of the transportation assets at risk in the Georgia coastal area. The study forms a basis for future investigation of hurricane impacts on the transportation system of the Georgia coast and facilitates the design of mitigation and adaptation plans for this area.

APPENDIX A

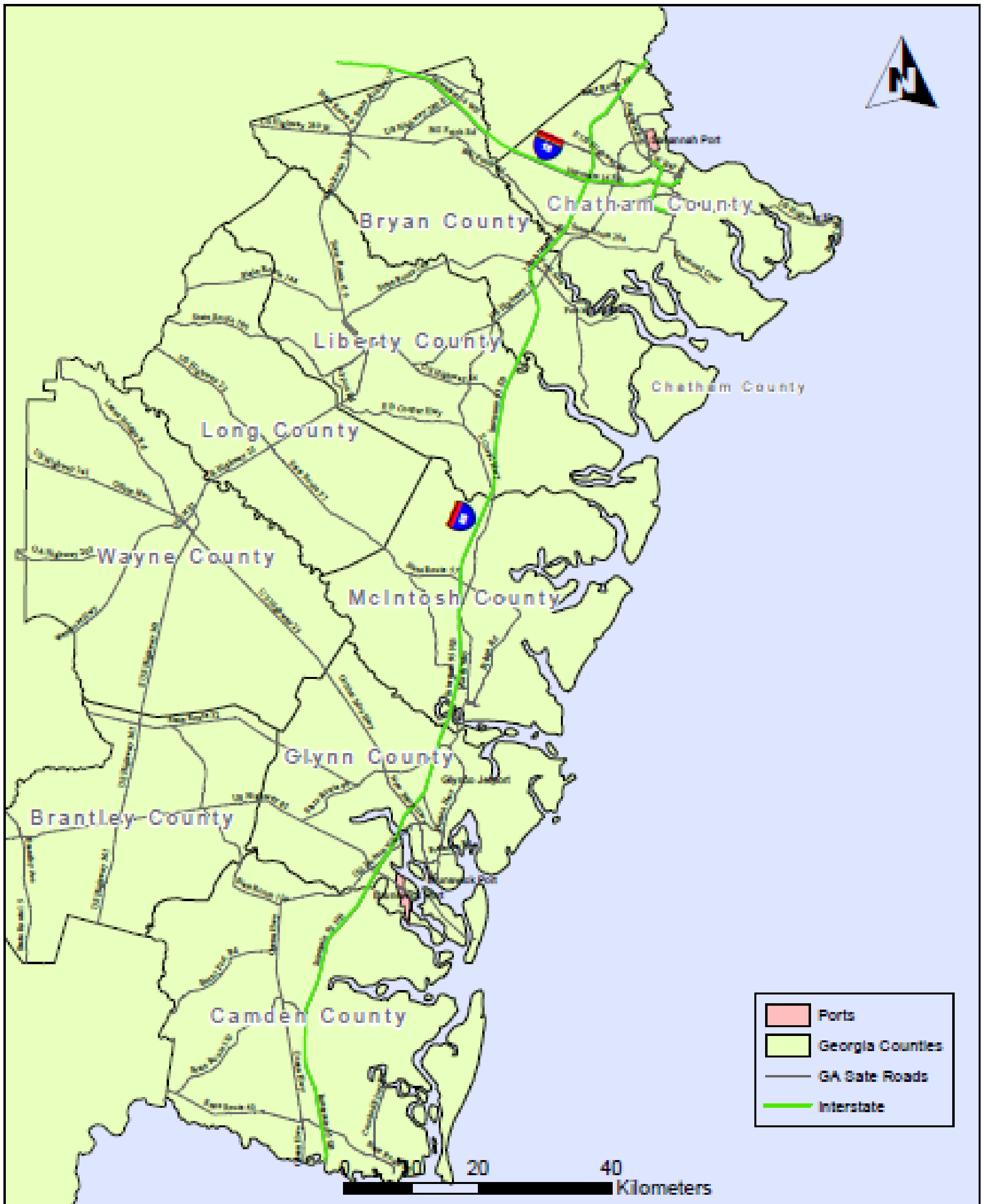
SAFFIR-SIMPSON HURRICANE WIND SCALE

Category	Winds (1 min sustained winds in mph, kt, and km/hr)	Summary	People, Livestock, and Pets	Mobile Homes	Frame Homes	Apartments, Shopping Centers, and Industrial Buildings	High-Rise Windows and Glass	Signage, Fences, and Canopies	Trees	Power and Water	Example
1	74-95 mph 64-82 kt 119-153 km/hr	*Very dangerous winds will produce some damage*	People, livestock, and pets struck by flying or falling debris could be injured or killed.	Older (mainly pre-1994 construction) mobile homes could be destroyed, especially if they are not anchored properly as they tend to shift or roll off their foundations. Newer mobile homes that are anchored properly can sustain damage involving the removal of shingle or metal roof coverings, and loss of vinyl siding, as well as damage to carports, sunrooms, or lanais.	Some poorly constructed frame homes can experience major damage, involving loss of the roof covering and damage to gable ends as well as the removal of porch coverings and awnings. Unprotected windows may break if struck by flying debris. Masonry chimneys can be toppled. Well-constructed frame homes could have damage to roof shingles, vinyl siding, soffit panels, and gutters. Failure of aluminum, screened-in, swimming pool enclosures can occur.	Some apartment building and shopping center roof coverings could be partially removed. Industrial buildings can lose roofing and siding especially from windward corners, rakes, and eaves. Failures to overhead doors and unprotected windows will be common.	Windows in high-rise buildings can be broken by flying debris. Falling and broken glass will pose a significant danger even after the storm.	There will be occasional damage to commercial signage, fences, and canopies.	Large branches of trees will snap and shallow rooted trees can be toppled.	Extensive damage to power lines and poles will likely result in power outages that could last a few to several days.	Hurricane Dolly (2008) is an example of a hurricane that brought Category 1 winds and impacts to South Padre Island, Texas.
2	96-110 mph 83-95 kt 154-177 km/hr	*Extremely dangerous winds will cause extensive damage*	There is a substantial risk of injury or death to people, livestock, and pets due to flying and falling debris.	Older (mainly pre-1994 construction) mobile homes have a very high chance of being destroyed and the flying debris generated can shred nearby mobile homes. Newer mobile homes can also be destroyed.	Poorly constructed frame homes have a high chance of having their roof structures removed especially if they are not anchored properly. Unprotected windows will have a high probability of being broken by flying debris. Well-constructed frame homes could sustain major roof and siding damage. Failure of aluminum, screened-in, swimming pool enclosures will be common.	There will be a substantial percentage of roof and siding damage to apartment buildings and industrial buildings. Unreinforced masonry walls can collapse.	Windows in high-rise buildings can be broken by flying debris. Falling and broken glass will pose a significant danger even after the storm.	Commercial signage, fences, and canopies will be damaged and often destroyed.	Many shallowly rooted trees will be snapped or uprooted and block numerous roads.	Near-total power loss is expected with outages that could last from several days to weeks. Potable water could become scarce as filtration systems begin to fail.	Hurricane Frances (2004) is an example of a hurricane that brought Category 2 winds and impacts to coastal portions of Port St. Lucie, Florida with Category 1 conditions experienced elsewhere in the city.
3	111-130 mph 96-113 kt 178-209 km/hr	*Devastating damage will occur*	There is a high risk of injury or death to people, livestock, and pets due to flying and falling debris.	Nearly all older (pre-1994) mobile homes will be destroyed. Most newer mobile homes will sustain severe damage with potential for complete roof failure and wall collapse.	Poorly constructed frame homes can be destroyed by the removal of the roof and exterior walls. Unprotected windows will be broken by flying debris. Well-built frame homes can experience major damage involving the removal of roof decking and gable ends.	There will be a high percentage of roof covering and siding damage to apartment buildings and industrial buildings. Isolated structural damage to wood or steel framing can occur. Complete failure of older metal buildings is possible, and older unreinforced masonry buildings can collapse.	Numerous windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm.	Most commercial signage, fences, and canopies will be destroyed.	Many trees will be snapped or uprooted, blocking numerous roads.	Electricity and water will be unavailable for several days to a few weeks after the storm passes.	Hurricane Ivan (2004) is an example of a hurricane that brought Category 3 winds and impacts to coastal portions of Gulf Shores, Alabama with Category 2 conditions experienced elsewhere in this city.
4	131-155 mph 114-135 kt 210-249 km/hr	*Catastrophic damage will occur*	There is a very high risk of injury or death to people, livestock, and pets due to flying and falling debris.	Nearly all older (pre-1994) mobile homes will be destroyed. A high percentage of newer mobile homes also will be destroyed.	Poorly constructed homes can sustain complete collapse of all walls as well as the loss of the roof structure. Well-built homes also can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Extensive damage to roof coverings, windows, and doors will occur. Large amounts of windborne debris will be lofted into the air. Windborne debris damage will break most unprotected windows and penetrate some protected windows.	There will be a high percentage of structural damage to the top floors of apartment buildings. Steel frames in older industrial buildings can collapse. There will be a high percentage of collapse to older unreinforced masonry buildings.	Most windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm.	Nearly all commercial signage, fences, and canopies will be destroyed.	Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas.	Power outages will last for weeks to possibly months. Long-term water shortages will increase human suffering. Most of the area will be uninhabitable for weeks or months.	Hurricane Charley (2004) is an example of a hurricane that brought Category 4 winds and impacts to coastal portions of Punta Gorda, Florida with Category 3 conditions experienced elsewhere in the city.
5	> 155 mph > 135 kt > 249 km/hr	*Catastrophic damage will occur*	People, livestock, and pets are at very high risk of injury or death from flying or falling debris, even if indoors in mobile homes or framed homes.	Almost complete destruction of all mobile homes will occur, regardless of age or construction.	A high percentage of frame homes will be destroyed, with total roof failure and wall collapse. Extensive damage to roof covers, windows, and doors will occur. Large amounts of windborne debris will be lofted into the air. Windborne debris damage will occur to nearly all unprotected windows and many protected windows.	Significant damage to wood roof commercial buildings will occur due to loss of roof sheathing. Complete collapse of many older metal buildings can occur. Most unreinforced masonry walls will fail which can lead to the collapse of the buildings. A high percentage of industrial buildings and low-rise apartment buildings will be destroyed.	Nearly all windows will be blown out of high-rise buildings resulting in falling glass, which will pose a threat for days to weeks after the storm.	Nearly all commercial signage, fences, and canopies will be destroyed.	Nearly all trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas.	Power outages will last for weeks to possibly months. Long-term water shortages will increase human suffering. Most of the area will be uninhabitable for weeks or months.	Hurricane Andrew (1992) is an example of a hurricane that brought Category 5 winds and impacts to coastal portions of Cutler Ridge, Florida with Category 4 conditions experienced elsewhere in south Miami-Dade County.

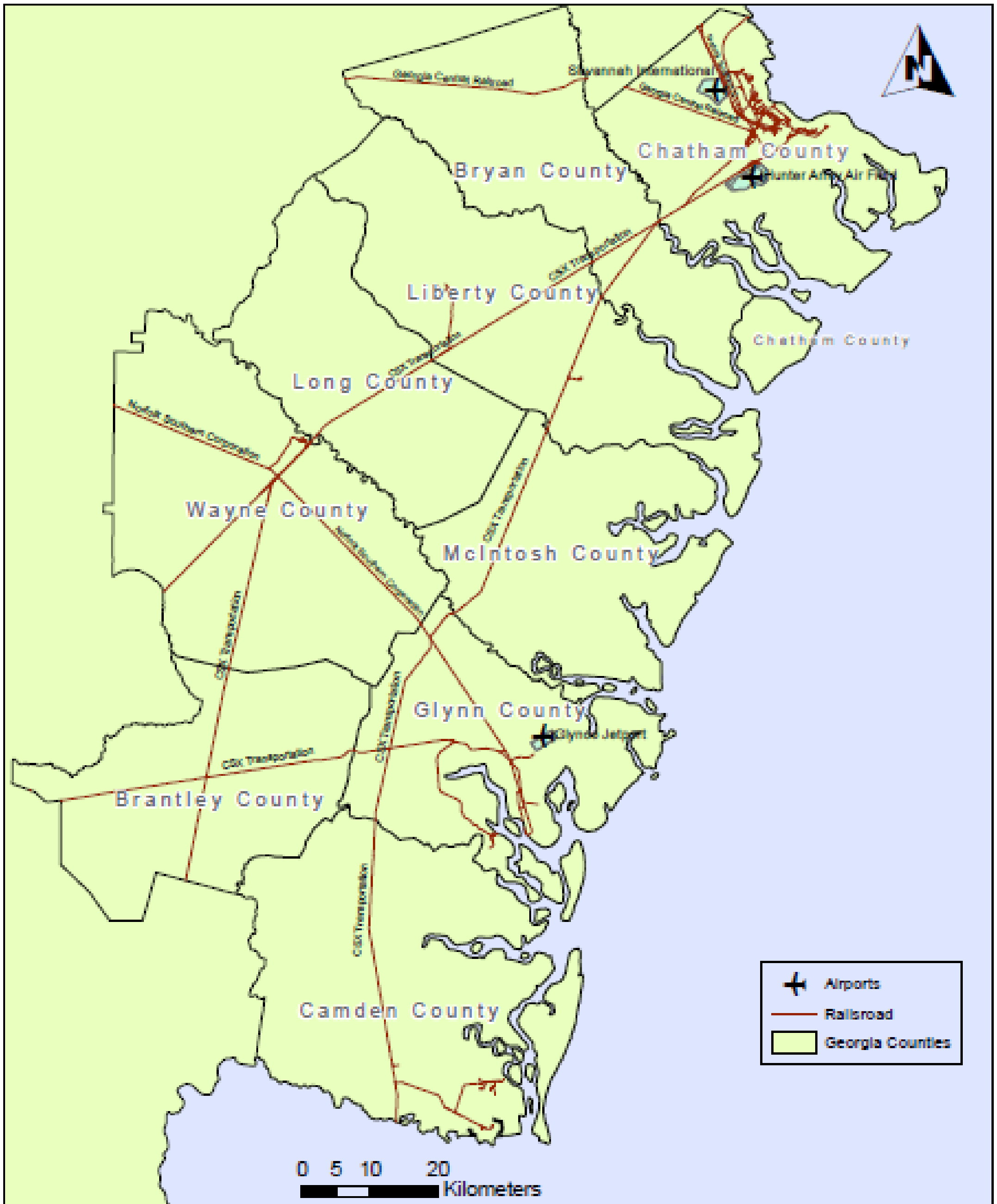
APPENDIX B

MAPS

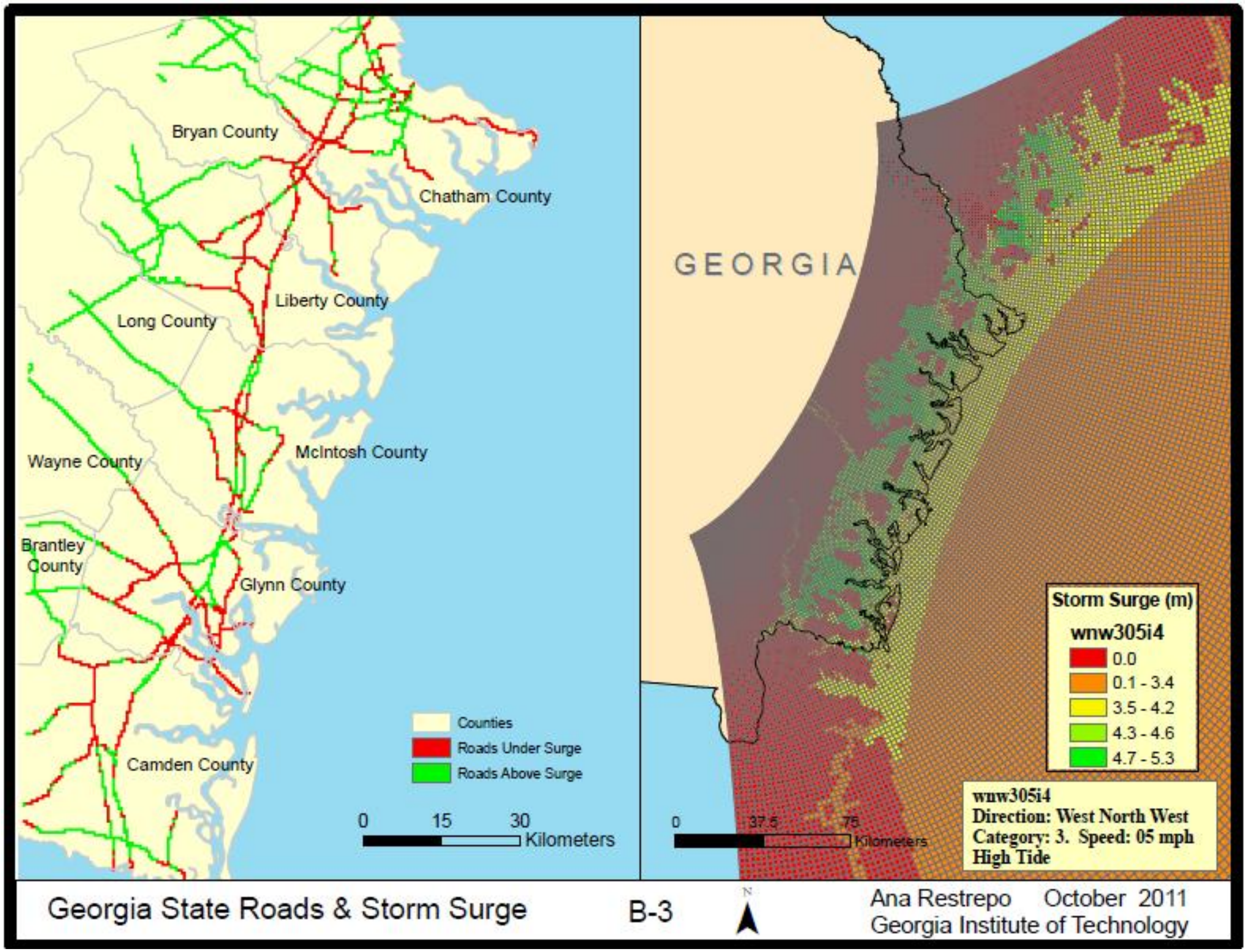
Map B1 and B2 show the Transportation assets of the Georgia Coast. Maps B3-B44 show the transportation assets affected by different possible storms.



Georgia Coast Ports and Roads B-1 Ana Restrepo October 2011 Georgia Institute of Technology



Georgia Coast Railroads and Airports B-2 Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Counties
Roads Under Surge
Roads Above Surge
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw305i4
0.0
0.1 - 3.4
3.5 - 4.2
4.3 - 4.6
4.7 - 5.3
wnw305i4
Direction: West North West
Category: 3. Speed: 05 mph
High Tide
0 37.5 75 Kilometers
Georgia State Roads & Storm Surge
B-3
N
Ana Restrepo October 2011
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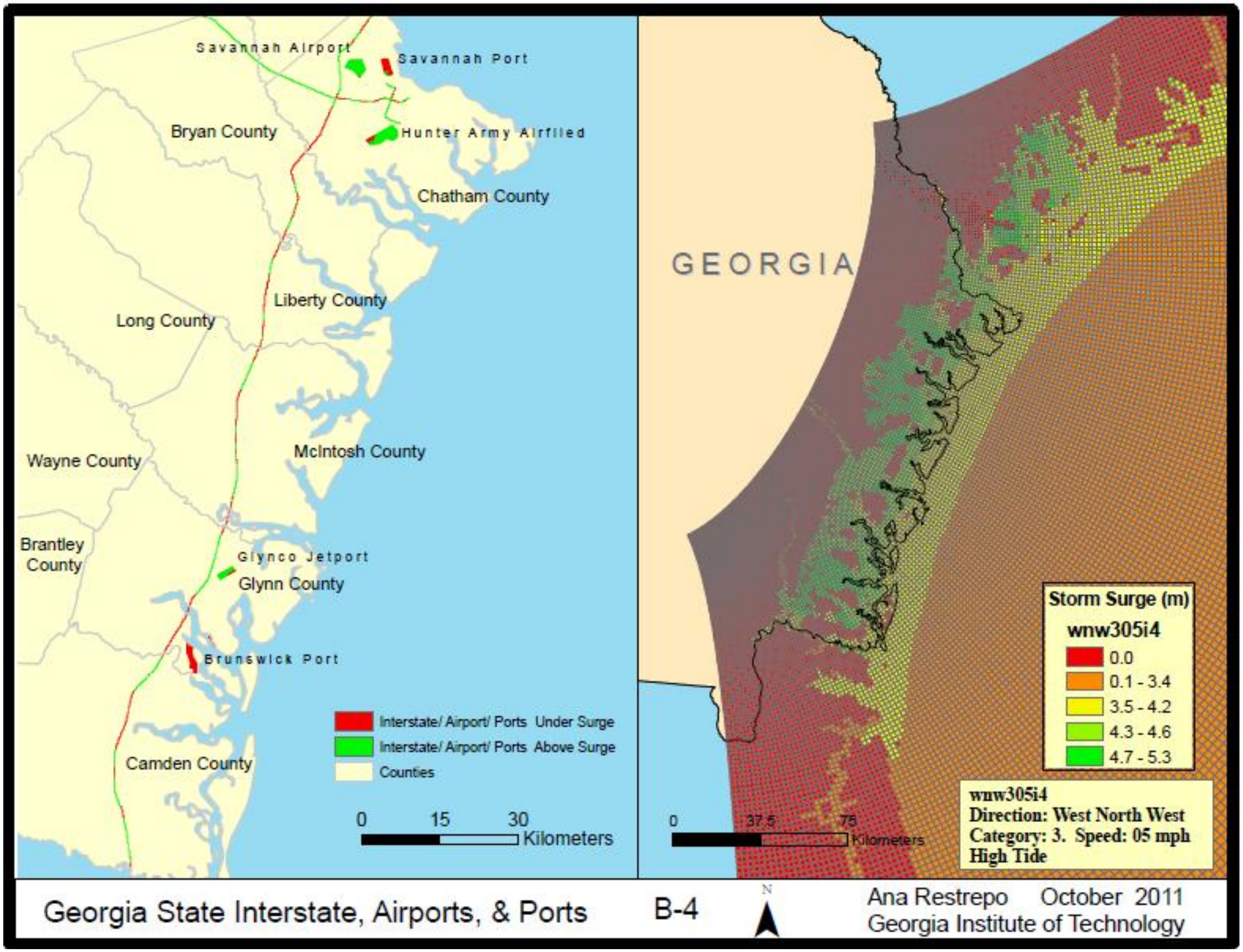
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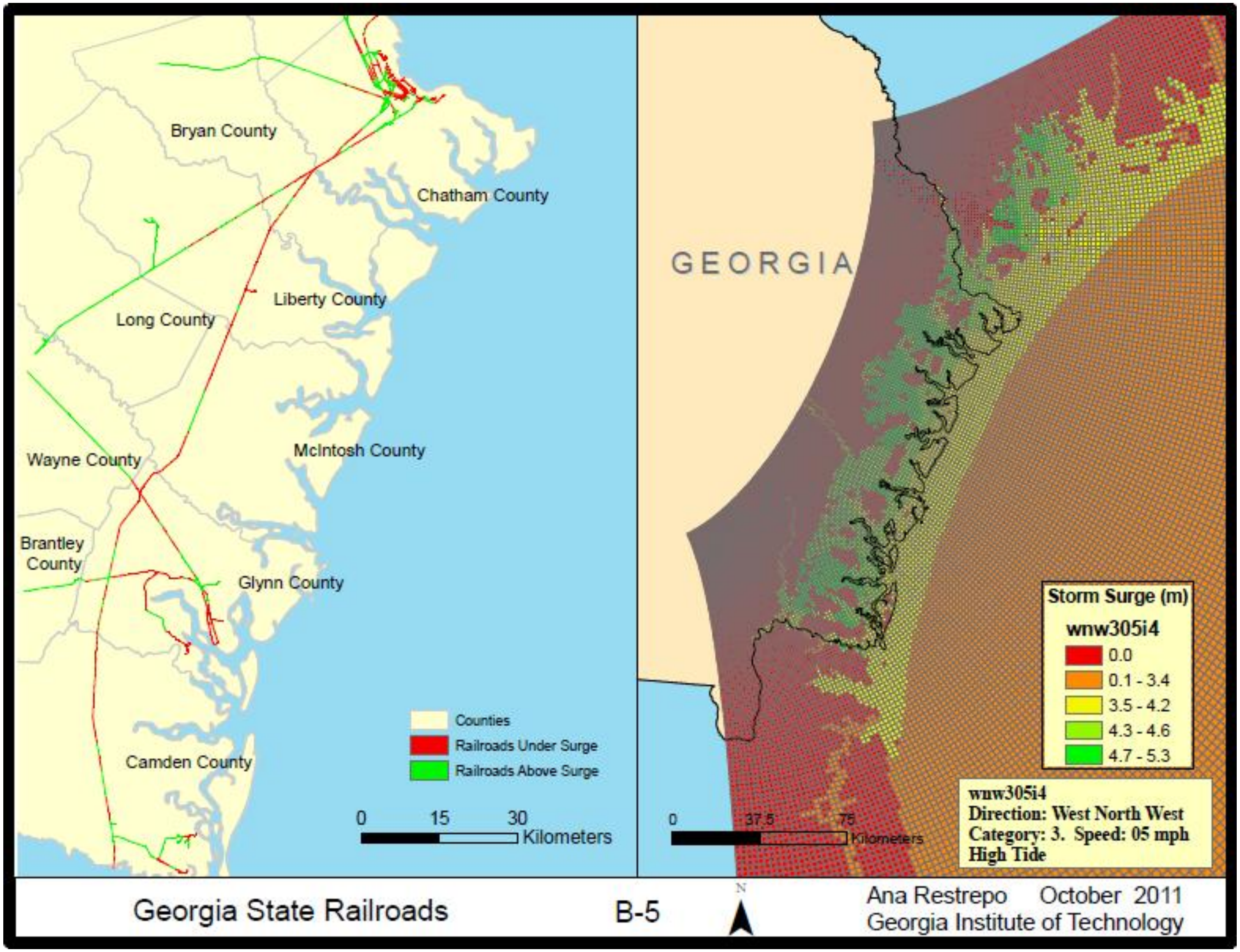
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airport/ Ports Under Surge
Interstate/ Airport/ Ports Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw305i4
0.0
0.1 - 3.4
3.5 - 4.2
4.3 - 4.6
4.7 - 5.3
0 37.5 75 Kilometers
wnw305i4
Direction: West North West
Category: 3. Speed: 05 mph
High Tide
Georgia State Interstate, Airports, & Ports
B-4
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
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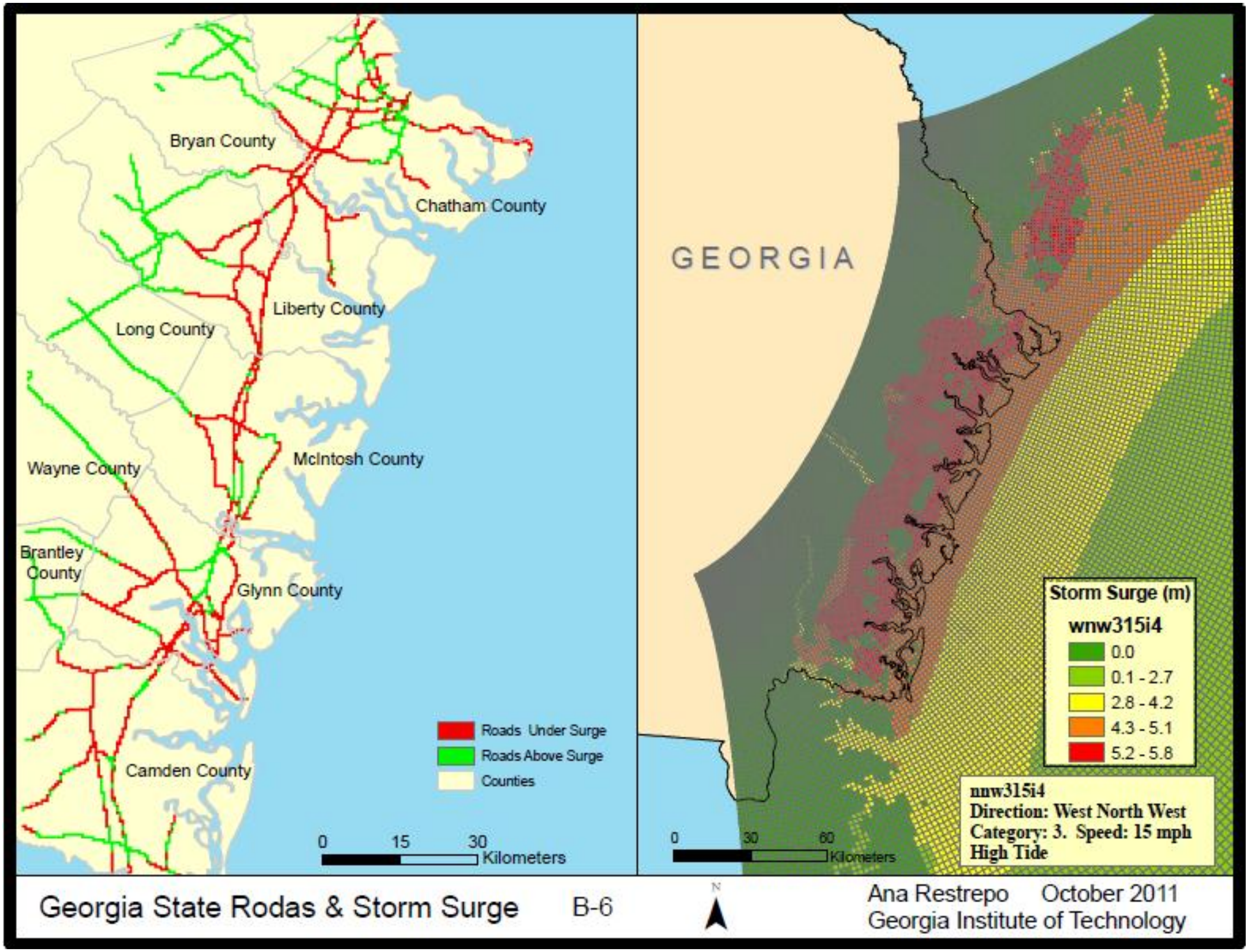
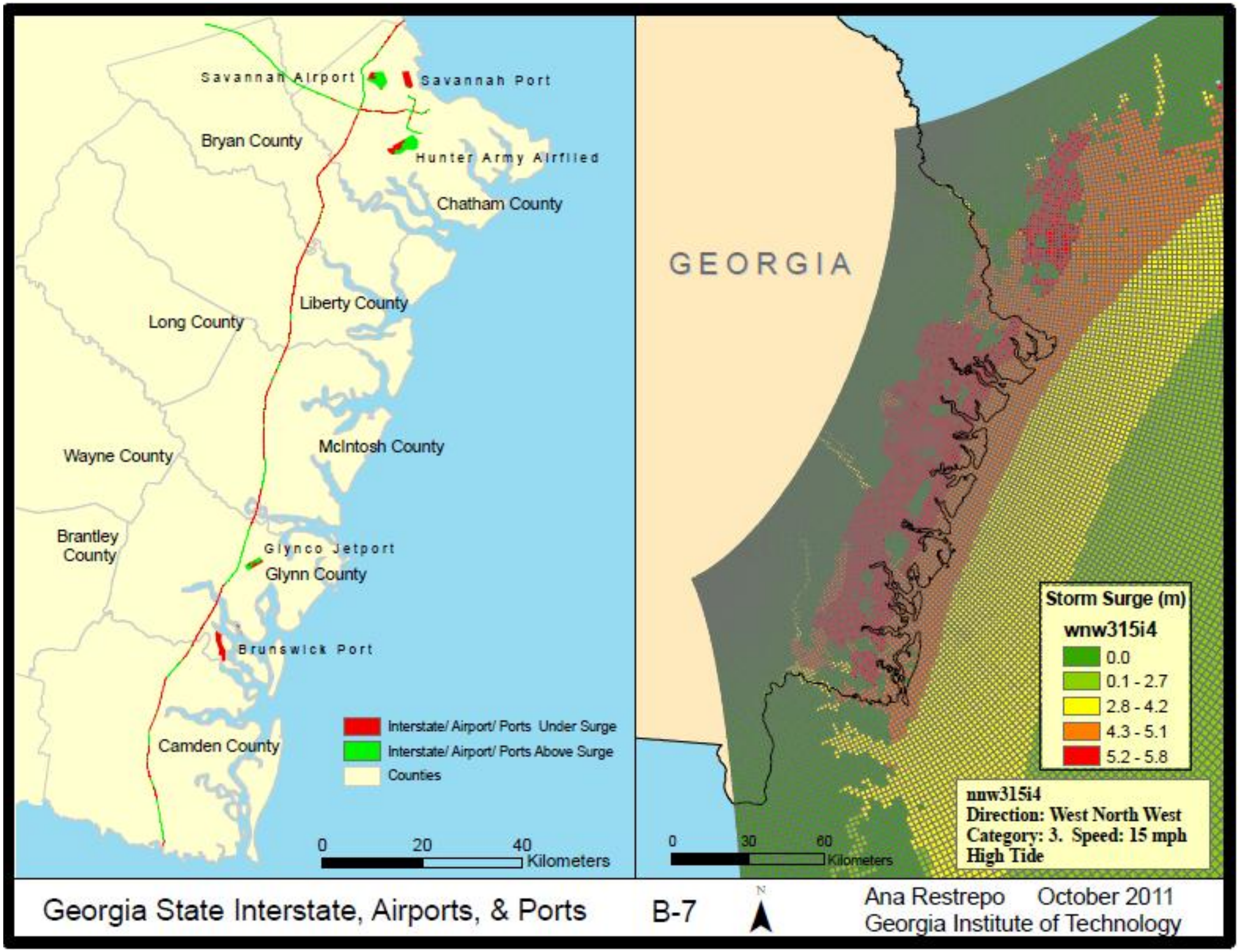
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Counties
Railroads Under Surge
Railroads Above Surge
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw305i4
0.0
0.1 - 3.4
3.5 - 4.2
4.3 - 4.6
4.7 - 5.3
0 37.5 75 Kilometers
wnw305i4
Direction: West North West
Category: 3. Speed: 05 mph
High Tide
Georgia State Railroads
B-5
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
Liberty County
Long County
Wayne County
McIntosh County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw315i4
0.0
0.1 - 2.7
2.8 - 4.2
4.3 - 5.1
5.2 - 5.8
nnw315i4
Direction: West North West
Category: 3. Speed: 15 mph
High Tide
0 30 60 Kilometers
Georgia State Rodas & Storm Surge
B-6
N
Ana Restrepo October 2011
Georgia Institute of Technology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Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airport/ Ports Under Surge
Interstate/ Airport/ Ports Above Surge
Counties
0 20 40 Kilometers
GEORGIA
Storm Surge (m)
wnw315i4
0.0
0.1 - 2.7
2.8 - 4.2
4.3 - 5.1
5.2 - 5.8
nnw315i4
Direction: West North West
Category: 3. Speed: 15 mph
High Tide
0 30 60 Kilometers
Georgia State Interstate, Airports, & Ports
B-7
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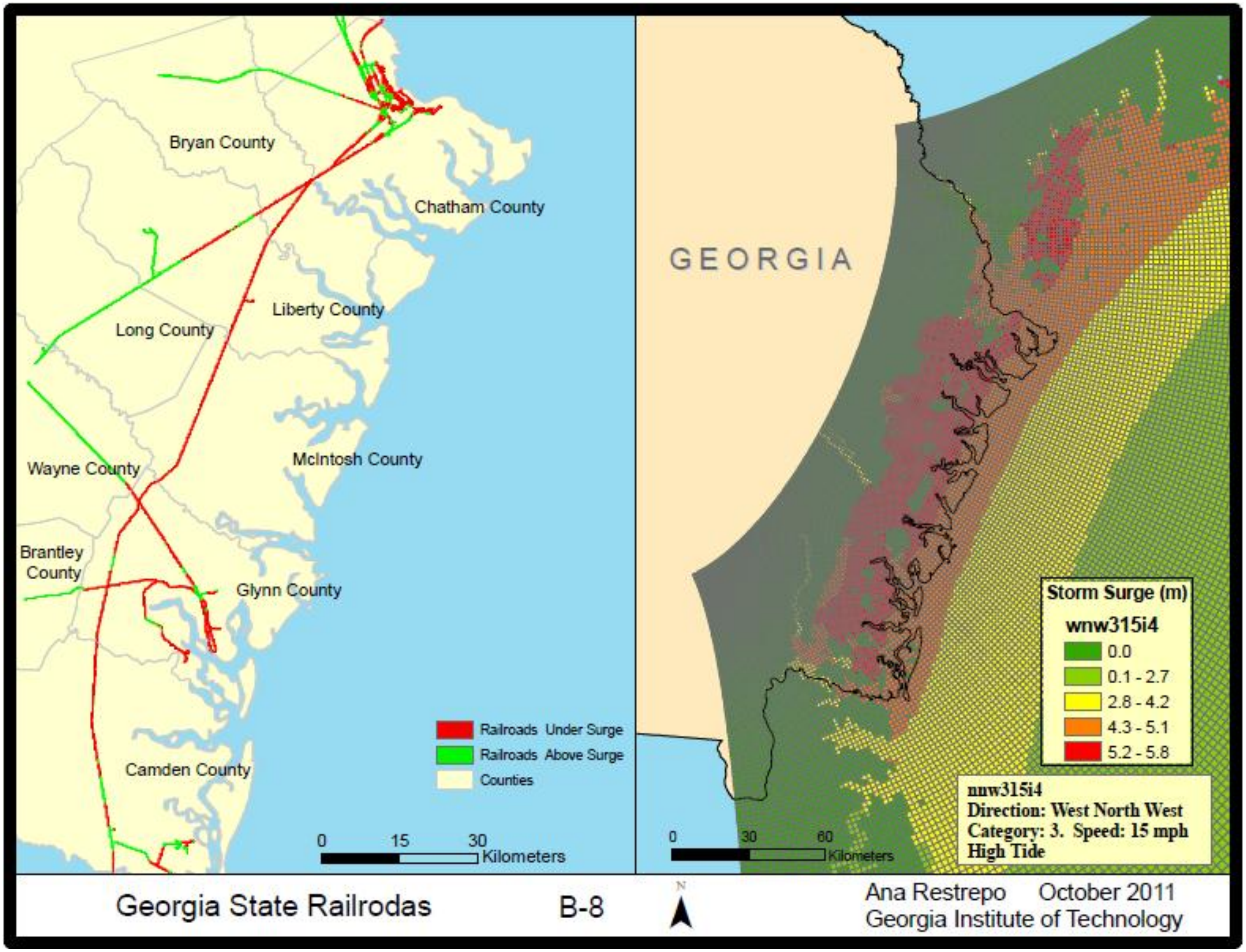
Ana Restrepo October 2011
Georgia Institute of Technology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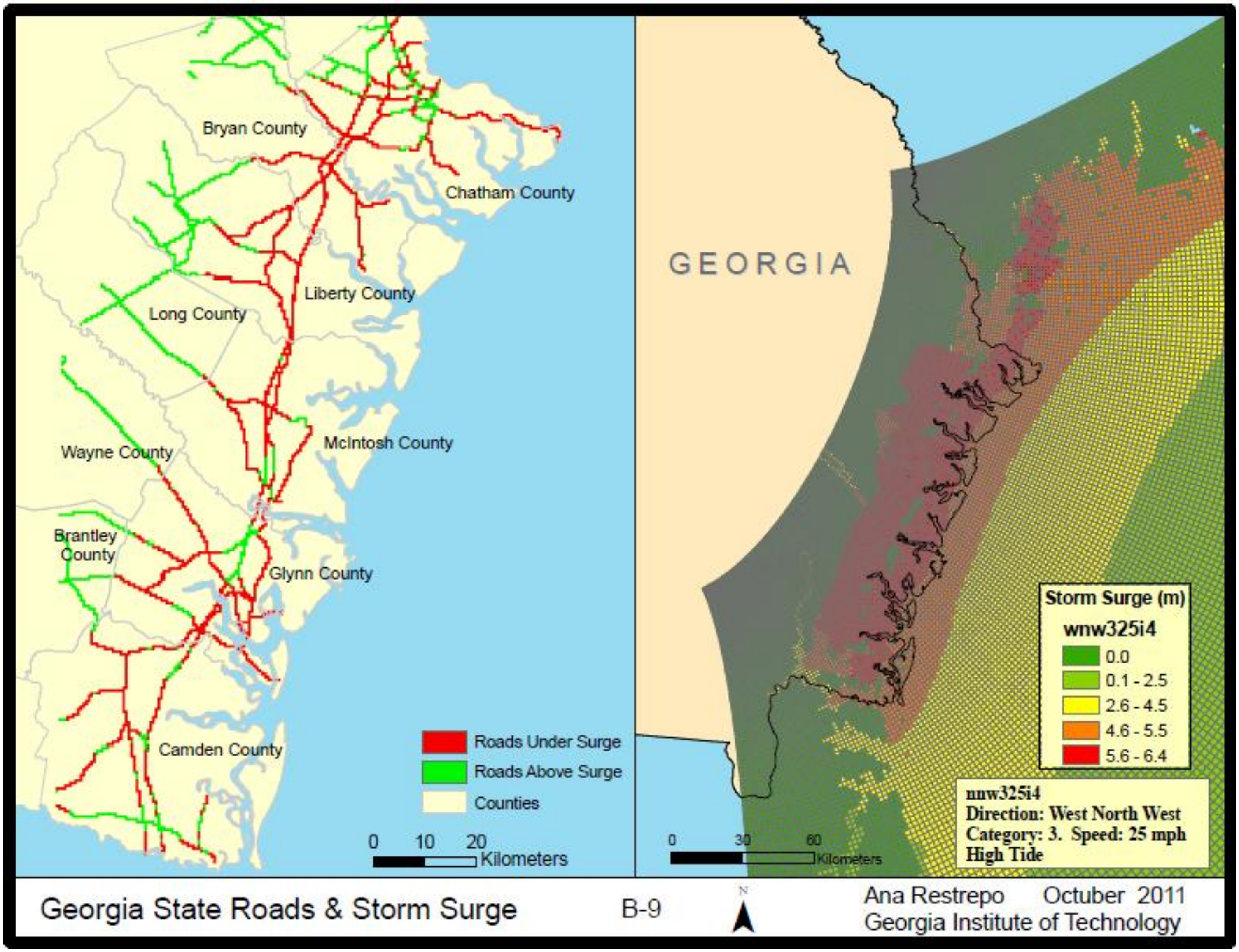
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw315i4
0.0
0.1 - 2.7
2.8 - 4.2
4.3 - 5.1
5.2 - 5.8
nnw315i4
Direction: West North West
Category: 3. Speed: 15 mph
High Tide
0 30 60 Kilometers
Georgia State Railrodas
B-8
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
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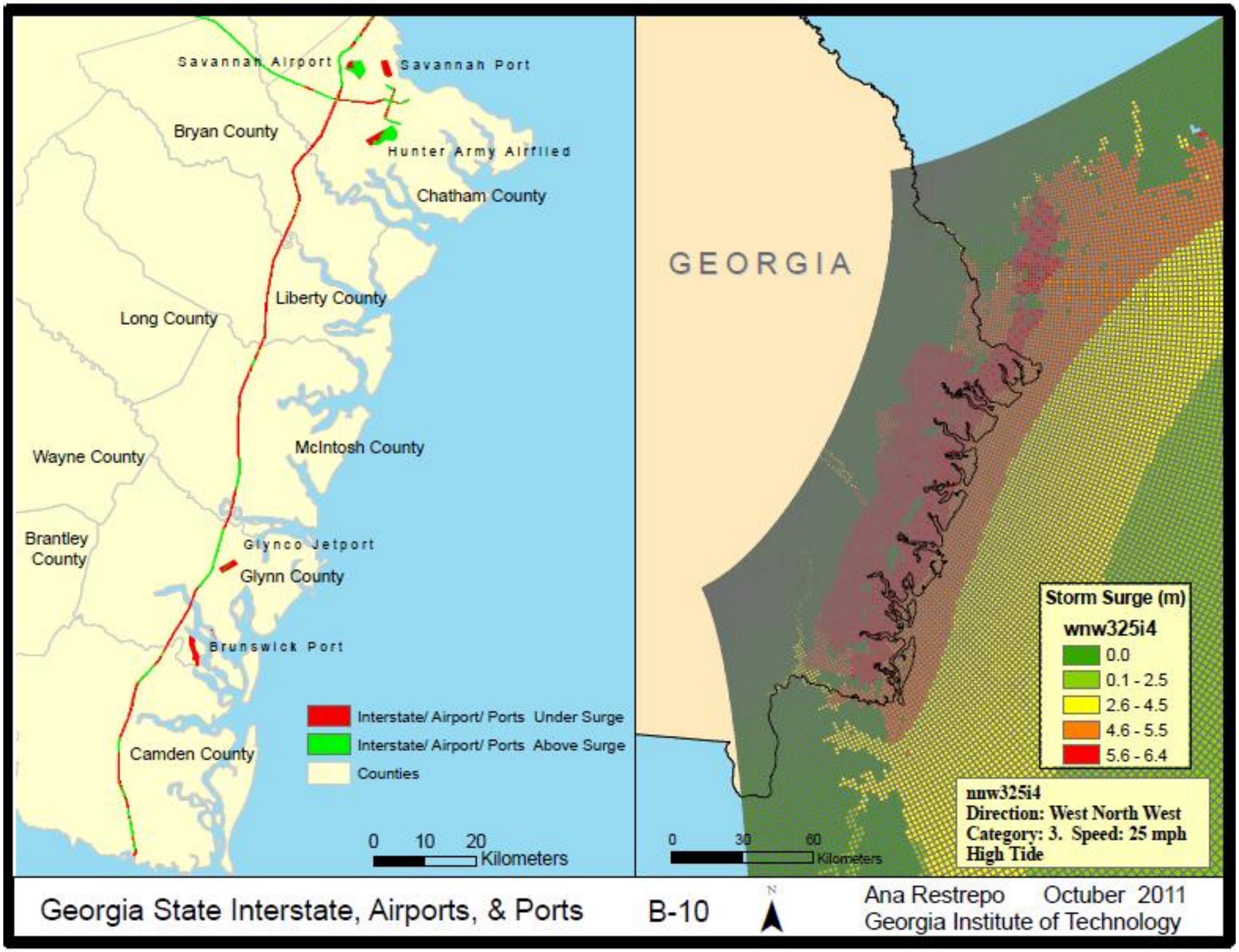
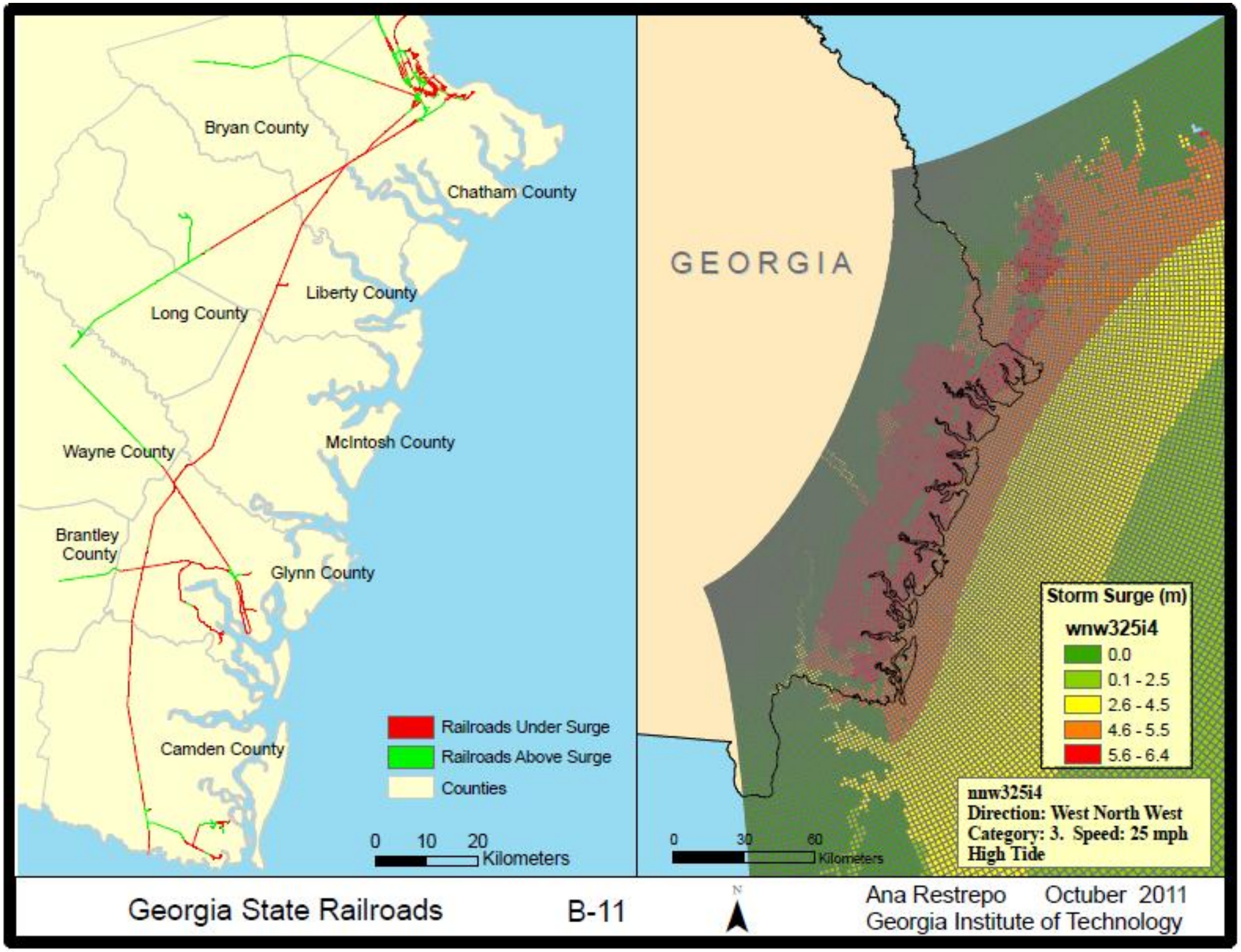
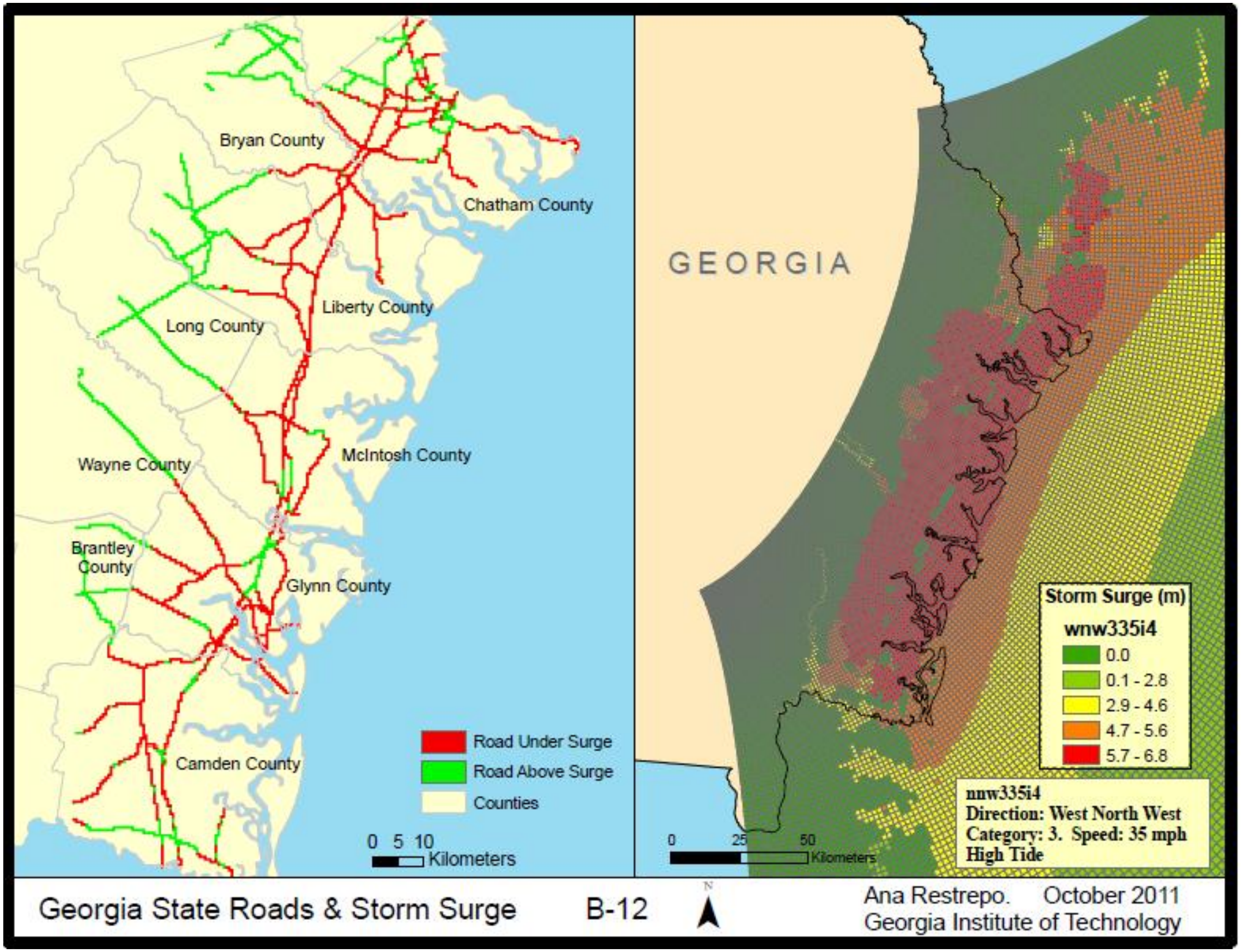
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 10 20 Kilometers
GEORGIA
Storm Surge (m)
wnw325i4
0.0
0.1 - 2.5
2.6 - 4.5
4.6 - 5.5
5.6 - 6.4
nnw325i4
Direction: West North West
Category: 3. Speed: 25 mph
High Tide
0 30 60 Kilometers
Georgia State Roads & Storm Surge
B-9
N
Ana Restrepo October 2011
Georgia Institute of Technology



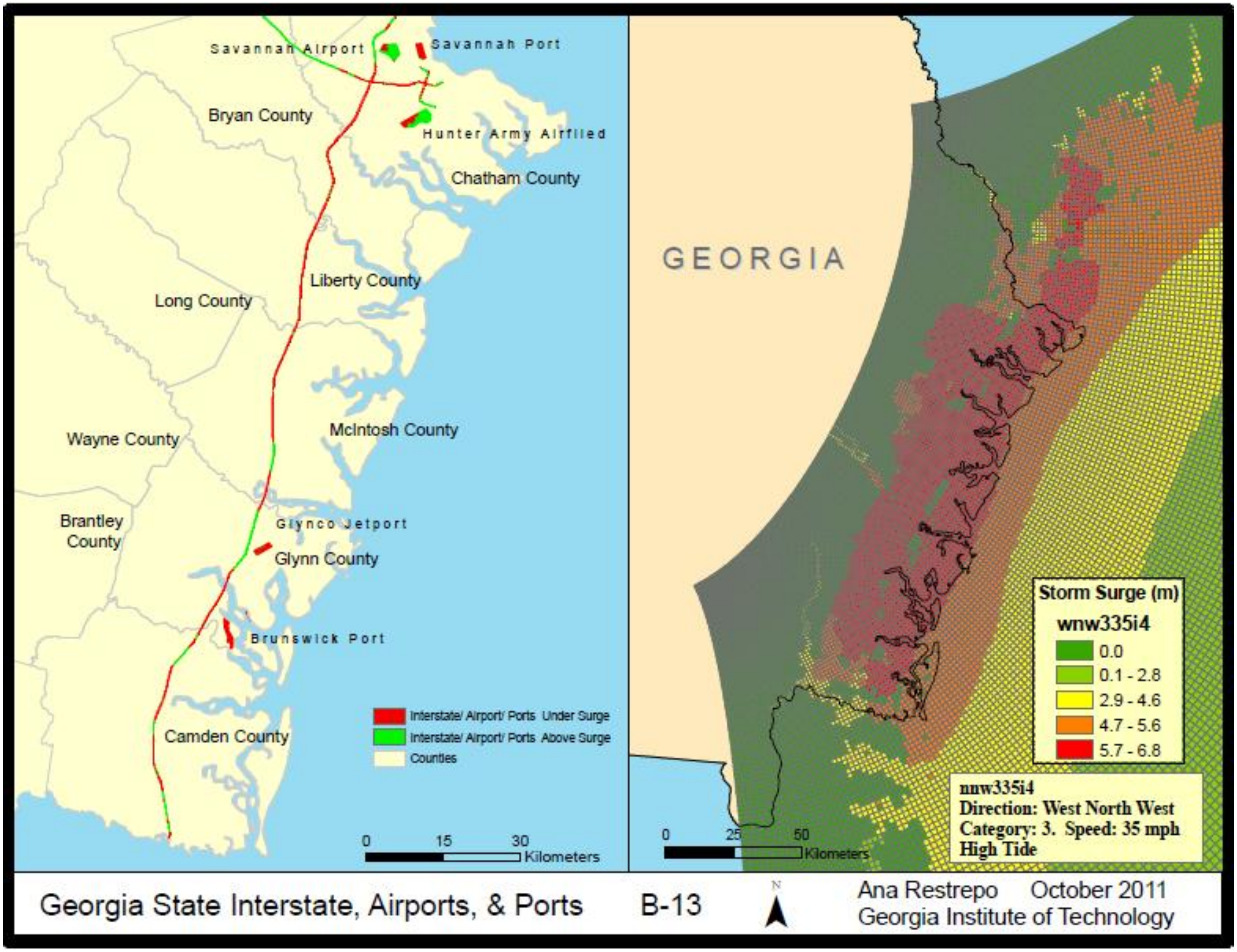
Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airport/ Ports Under Surge
Interstate/ Airport/ Ports Above Surge
Counties
0 10 20 Kilometers
GEORGIA
Storm Surge (m)
wnw325i4
0.0
0.1 - 2.5
2.6 - 4.5
4.6 - 5.5
5.6 - 6.4
nnw325i4
Direction: West North West
Category: 3. Speed: 25 mph
High Tide
0 30 60 Kilometers
Georgia State Interstate, Airports, & Ports
B-10
N
Ana Restrepo Octuber 2011
Georgia Institute of Technology



Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 10 20 Kilometers
GEORGIA
Storm Surge (m)
wnw325i4
0.0
0.1 - 2.5
2.6 - 4.5
4.6 - 5.5
5.6 - 6.4
wnw325i4
Direction: West North West
Category: 3. Speed: 25 mph
High Tide
0 30 60 Kilometers
Georgia State Railroads
B-11
N
Ana Restrepo Octuber 2011
Georgia Institute of Technology



Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Road Under Surge
Road Above Surge
Counties
0 5 10
Kilometers
GEORGIA
0 25 50
Kilometers
Storm Surge (m)
wnw335i4
0.0
0.1 - 2.8
2.9 - 4.6
4.7 - 5.6
5.7 - 6.8
nnw335i4
Direction: West North West
Category: 3. Speed: 35 mph
High Tide
Georgia State Roads & Storm Surge
B-12
N
Ana Restrepo. October 2011
Georgia Institute of Technology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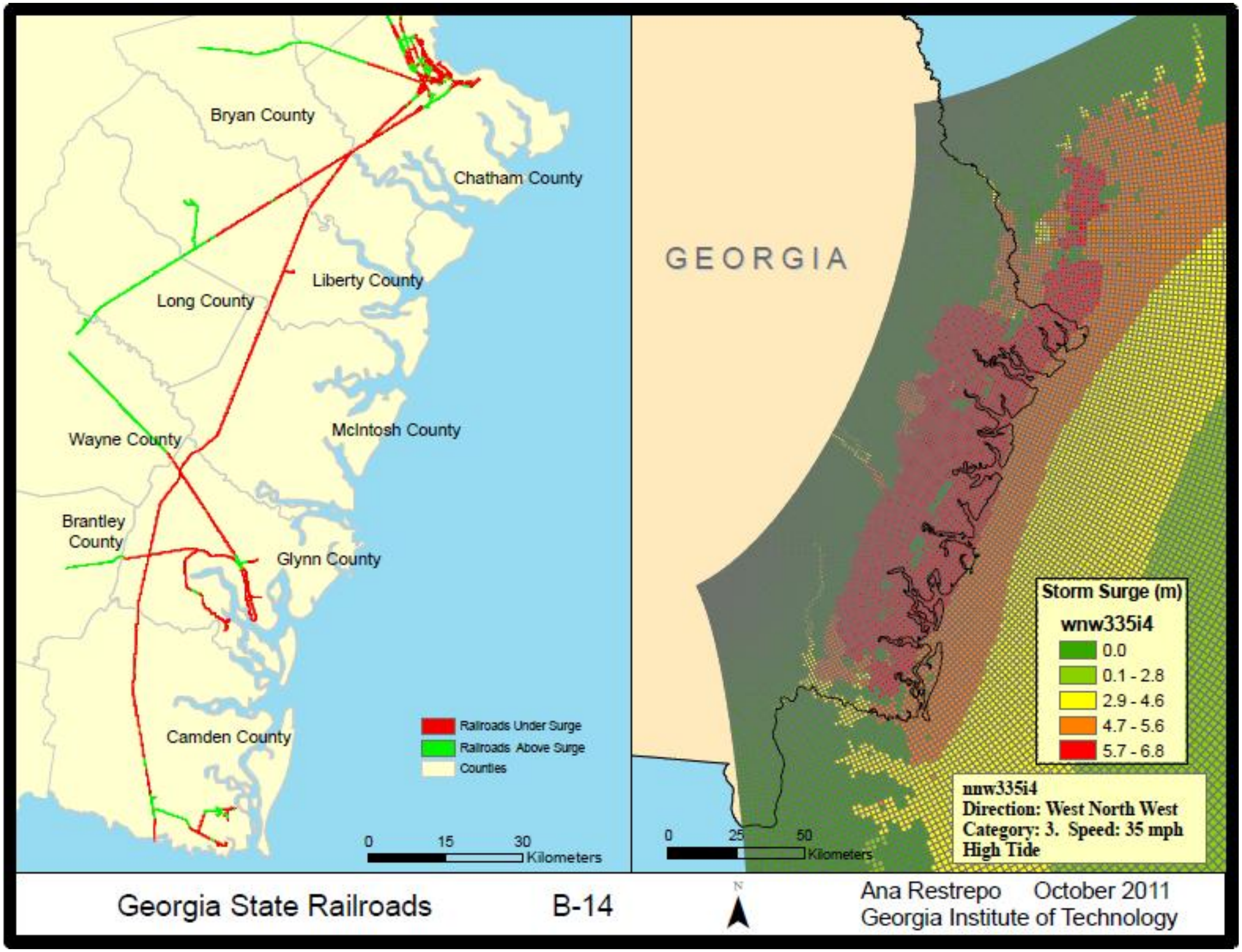
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airport/ Ports Under Surge
Interstate/ Airport/ Ports Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw335i4
0.0
0.1 - 2.8
2.9 - 4.6
4.7 - 5.6
5.7 - 6.8
0 25 50 Kilometers
nnw335i4
Direction: West North West
Category: 3. Speed: 35 mph
High Tide
Georgia State Interstate, Airports, & Ports
B-13
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
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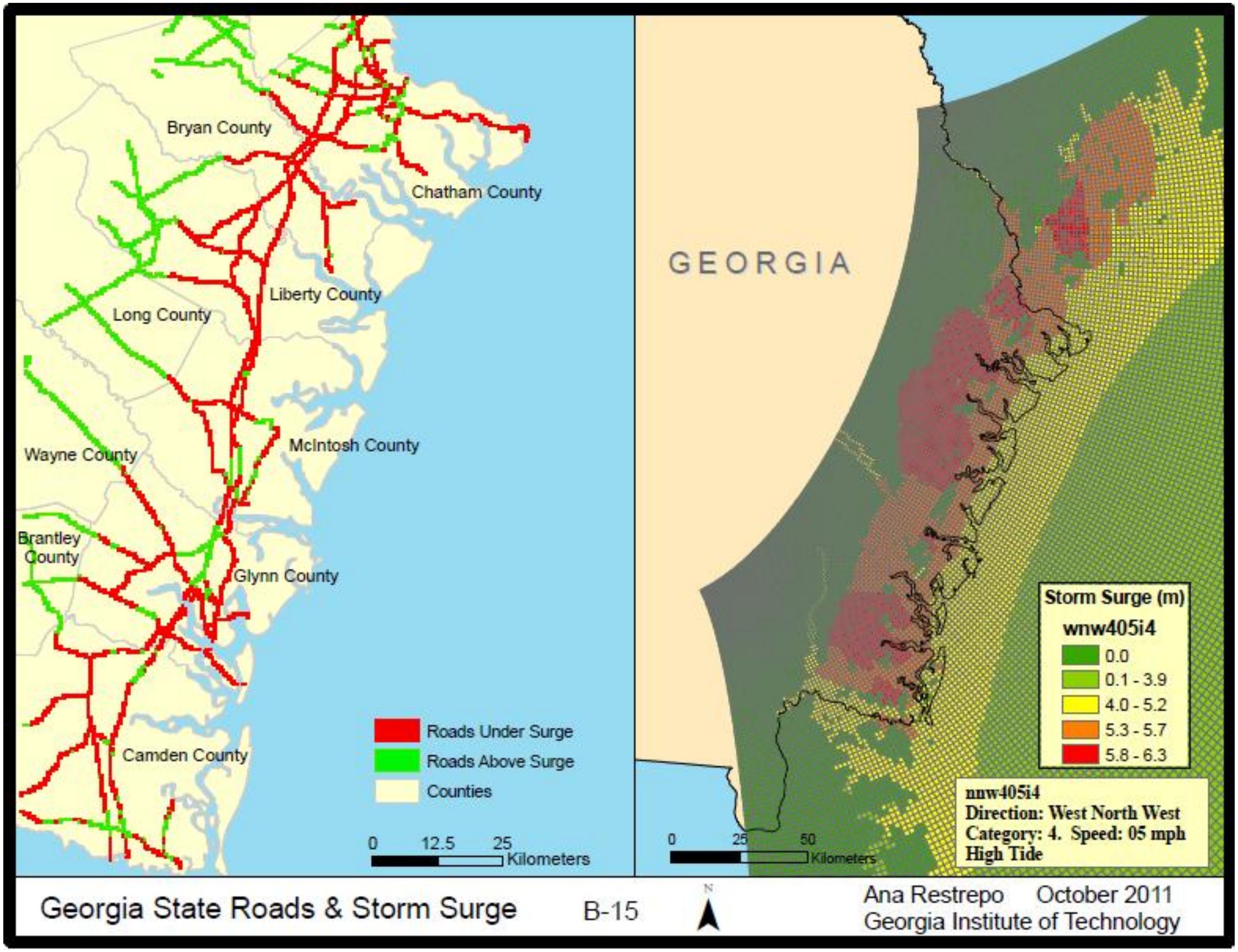
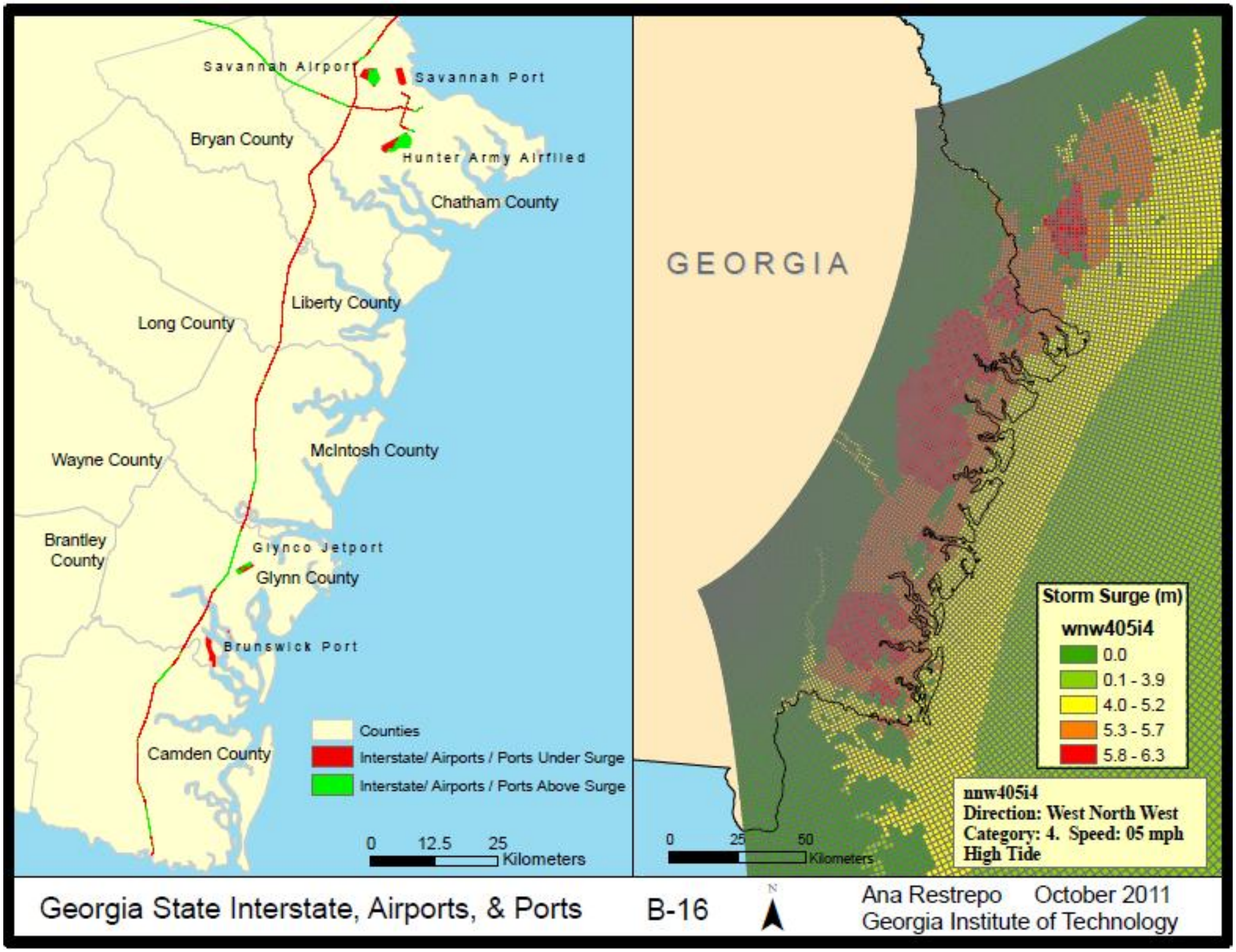
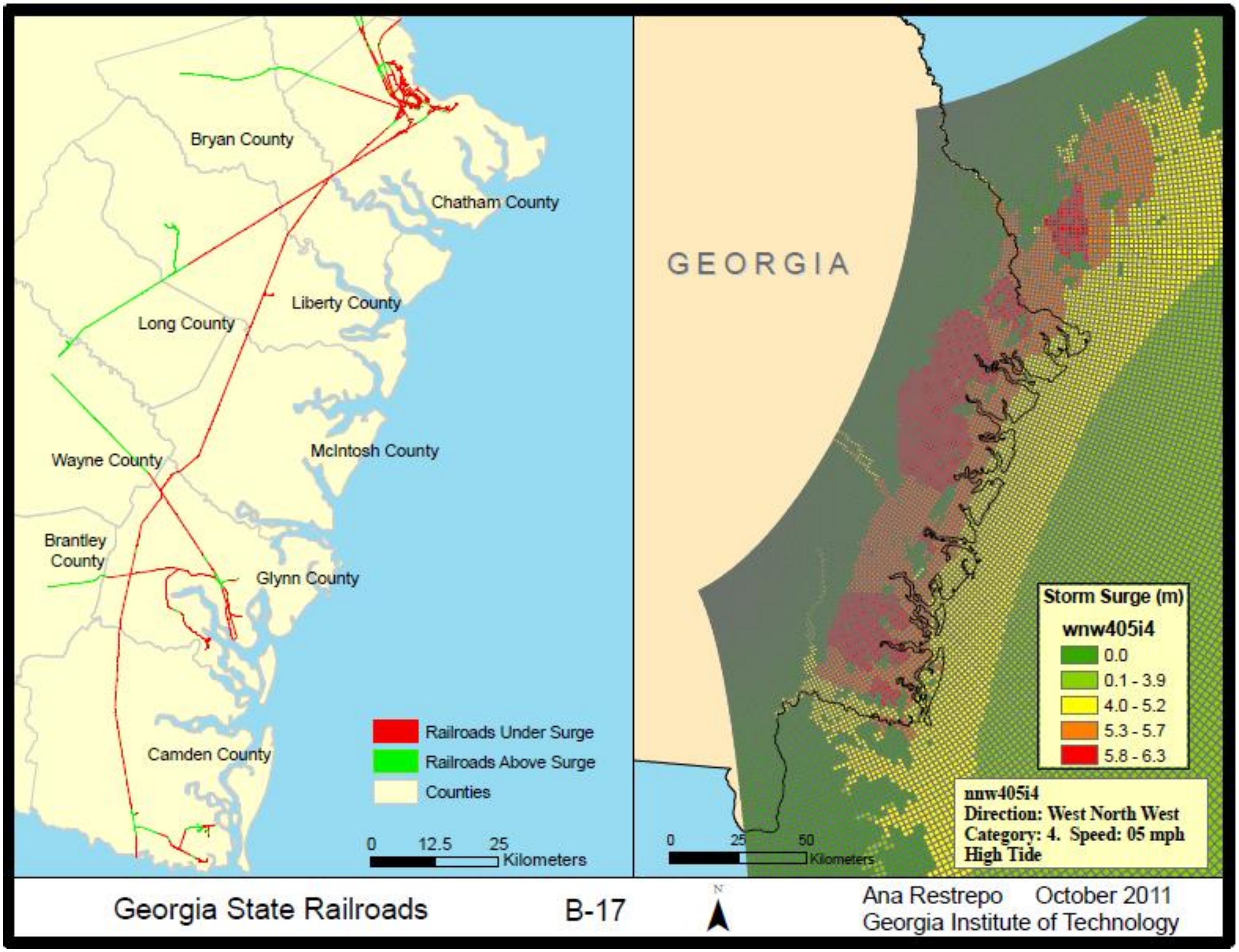
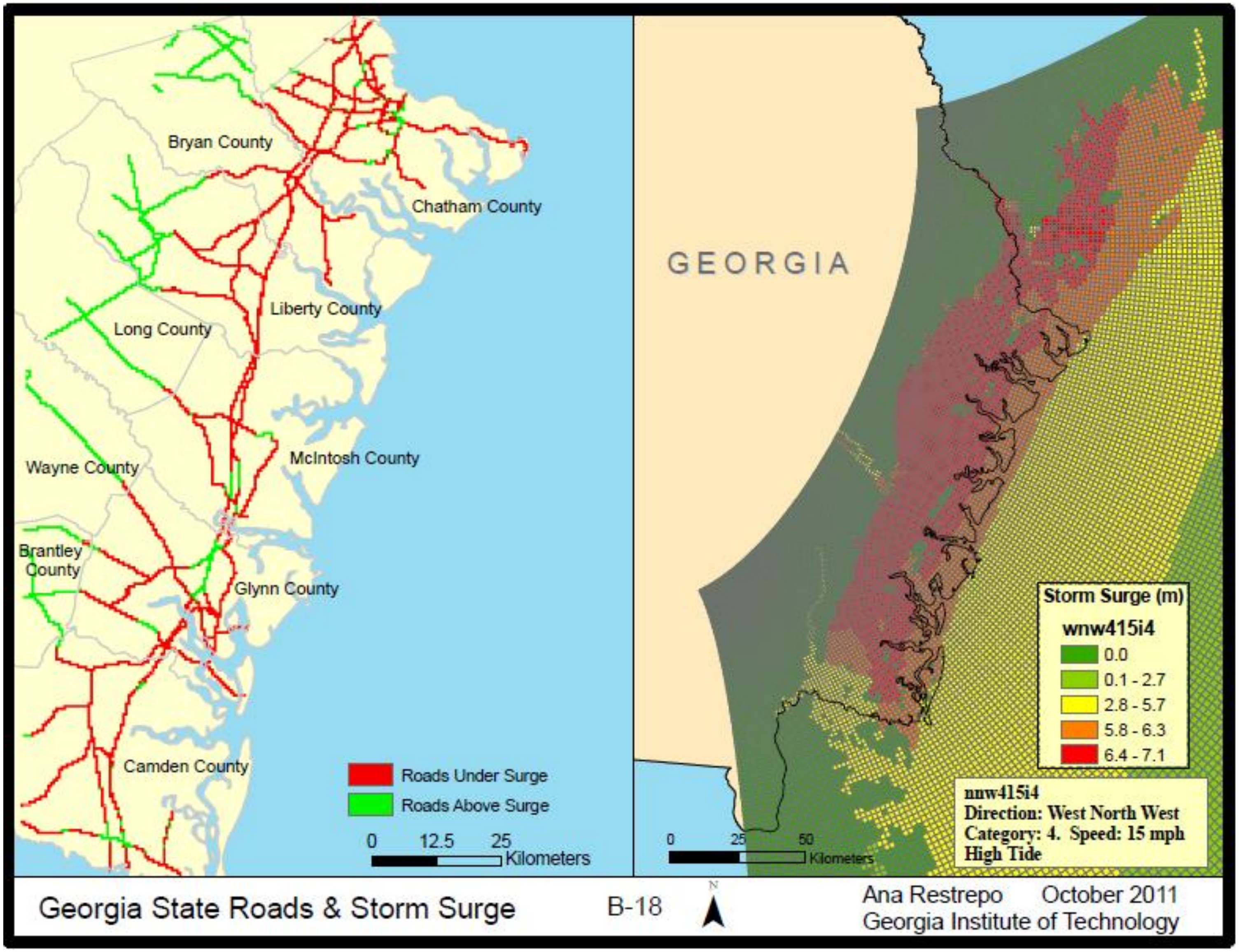
Long County
Wayne County
McIntosh County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw335i4
0.0
0.1 - 2.8
2.9 - 4.6
4.7 - 5.6
5.7 - 6.8
wnw335i4
Direction: West North West
Category: 3. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Railroads
B-14
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw405i4
0.0
0.1 - 3.9
4.0 - 5.2
5.3 - 5.7
5.8 - 6.3
nnw405i4
Direction: West North West
Category: 4. Speed: 05 mph
High Tide
0 25 50 Kilometers
Georgia State Roads & Storm Surge
B-15
N
Ana Restrepo October 2011
Georgia Institute of Technology

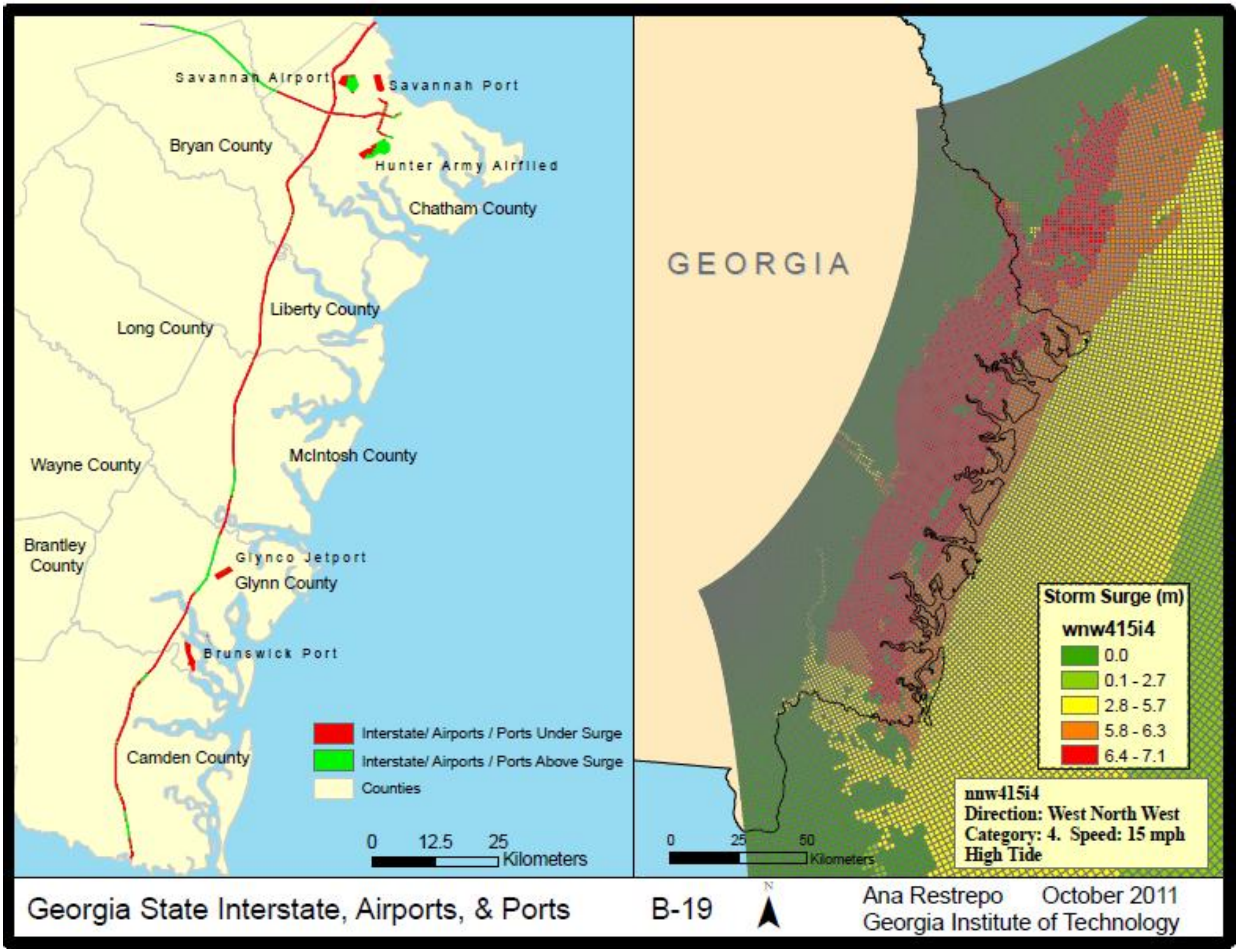

Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Counties
Interstate/ Airports / Ports Under Surge
Interstate/ Airports / Ports Above Surge
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw405i4
0.0
0.1 - 3.9
4.0 - 5.2
5.3 - 5.7
5.8 - 6.3
0 25 50 Kilometers
nnw405i4
Direction: West North West
Category: 4. Speed: 05 mph
High Tide
Georgia State Interstate, Airports, & Ports
B-16
N
Ana Restrepo October 2011
Georgia Institute of Technology



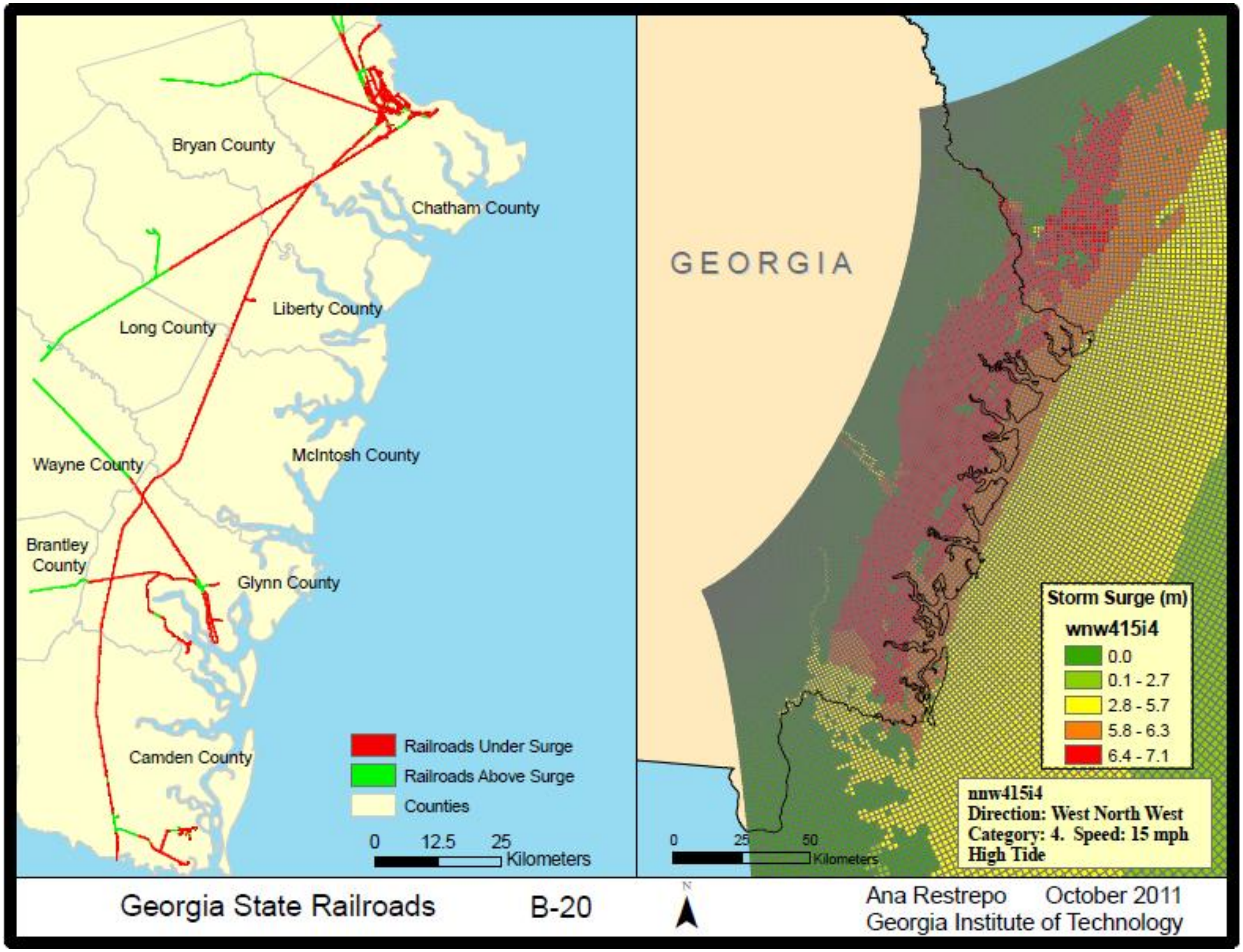
Bryan County
Chatham County
Liberty County
Long County
Wayne County
McIntosh County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw405i4
0.0
0.1 - 3.9
4.0 - 5.2
5.3 - 5.7
5.8 - 6.3
wnw405i4
Direction: West North West
Category: 4. Speed: 05 mph
High Tide
0 25 50 Kilometers
N
Georgia State Railroads
B-17
Ana Restrepo October 2011
Georgia Institute of Technology

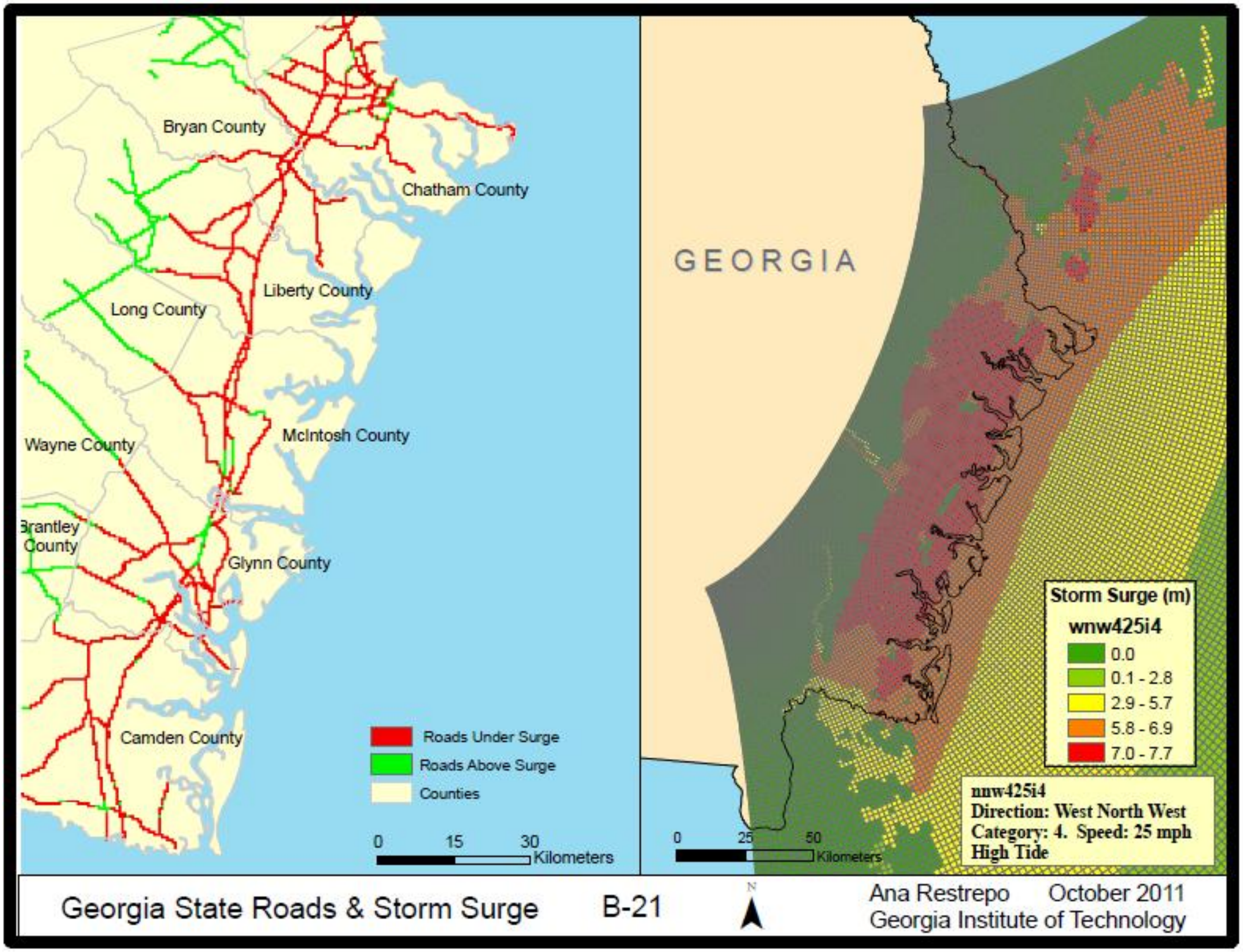


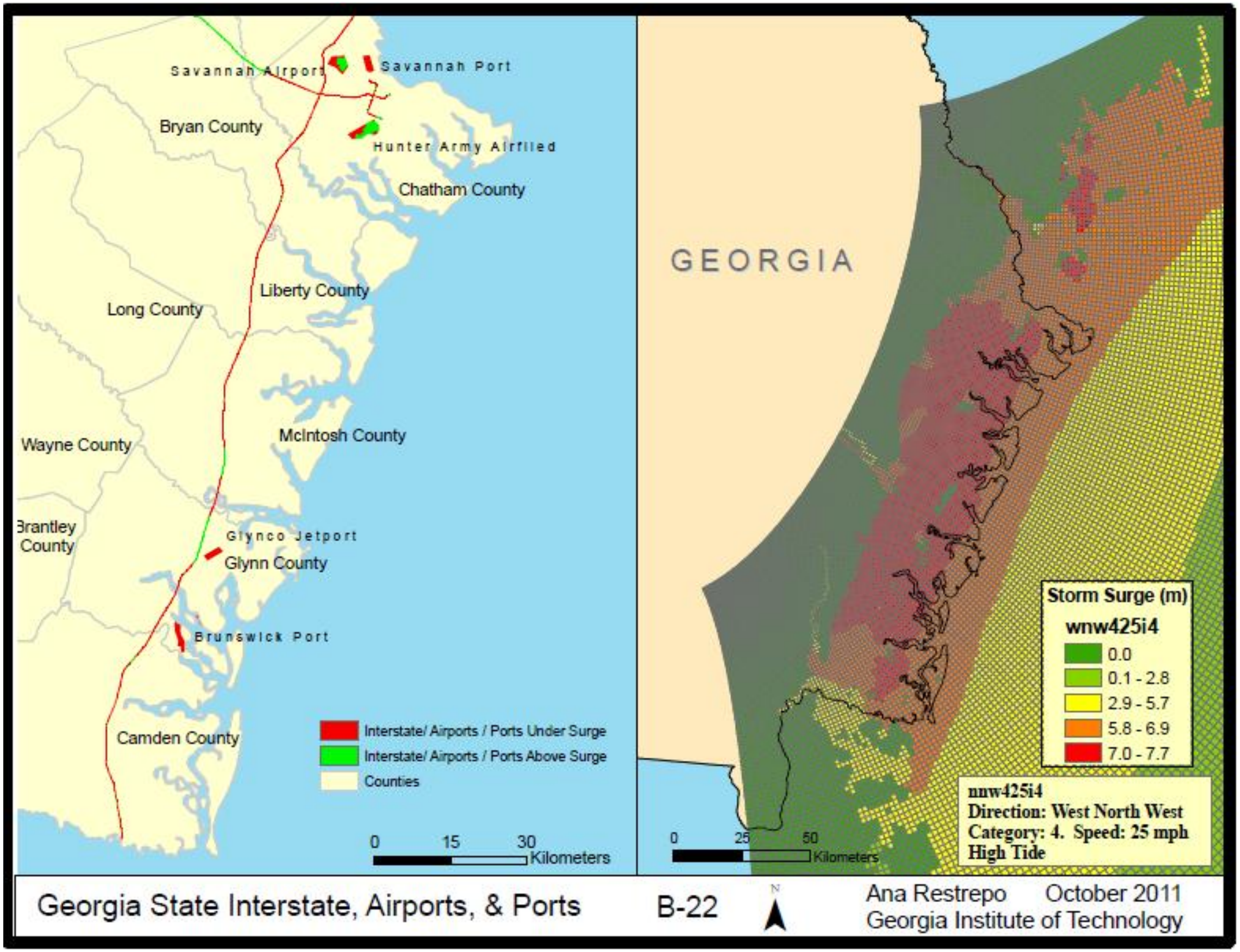
Bryan County
Chatham County
Liberty County
Long County
Wayne County
McIntosh County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw415i4
0.0
0.1 - 2.7
2.8 - 5.7
5.8 - 6.3
6.4 - 7.1
nnw415i4
Direction: West North West
Category: 4. Speed: 15 mph
High Tide
0 25 50 Kilometers
Georgia State Roads & Storm Surge
B-18
N
Ana Restrepo October 2011
Georgia Institute of Technology

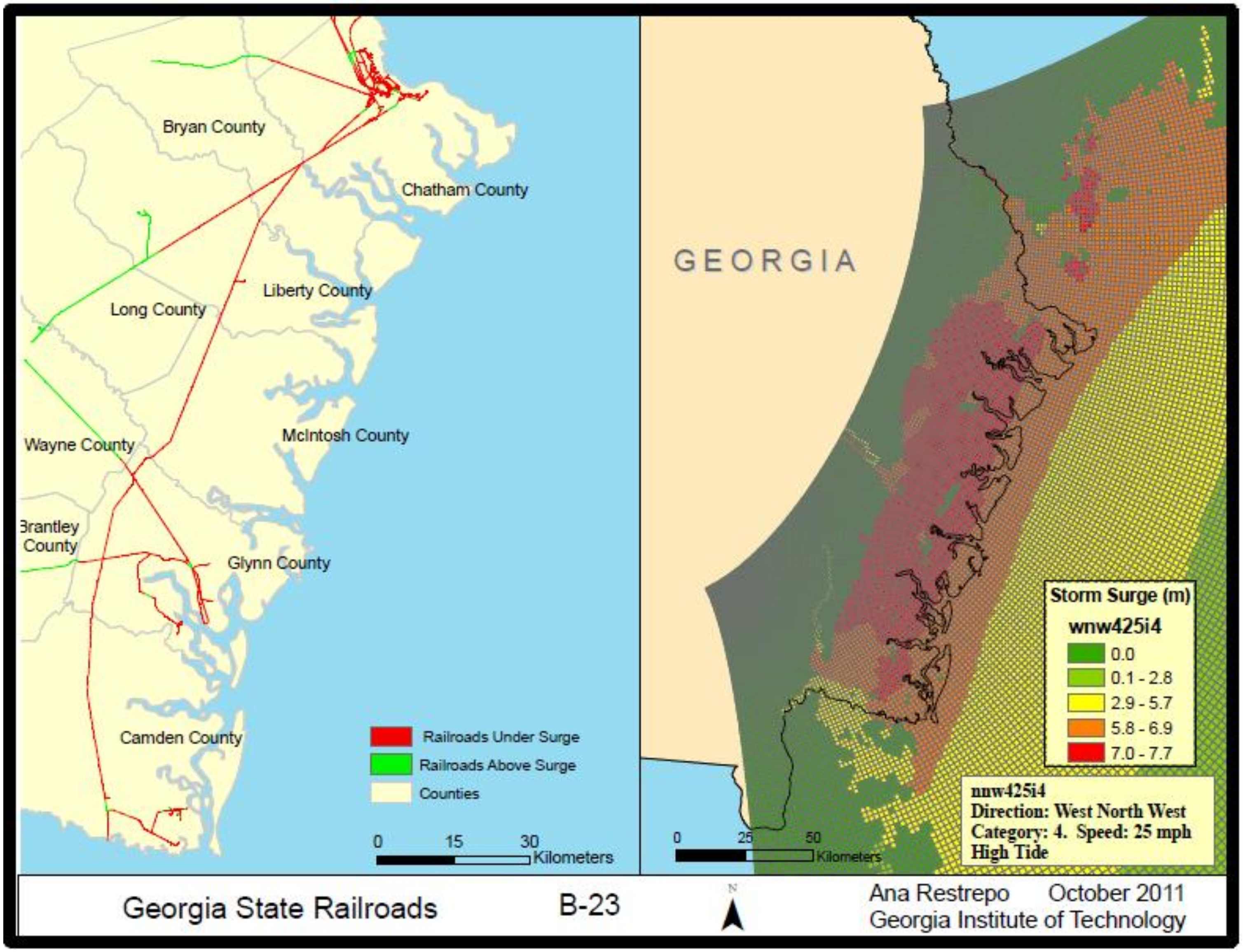


Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airports / Ports Under Surge
Interstate/ Airports / Ports Above Surge
Counties
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw415i4
0.0
0.1 - 2.7
2.8 - 5.7
5.8 - 6.3
6.4 - 7.1
nnw415i4
Direction: West North West
Category: 4. Speed: 15 mph
High Tide
0 25 50 Kilometers
Georgia State Interstate, Airports, & Ports
B-19
N
Ana Restrepo October 2011
Georgia Institute of Technology

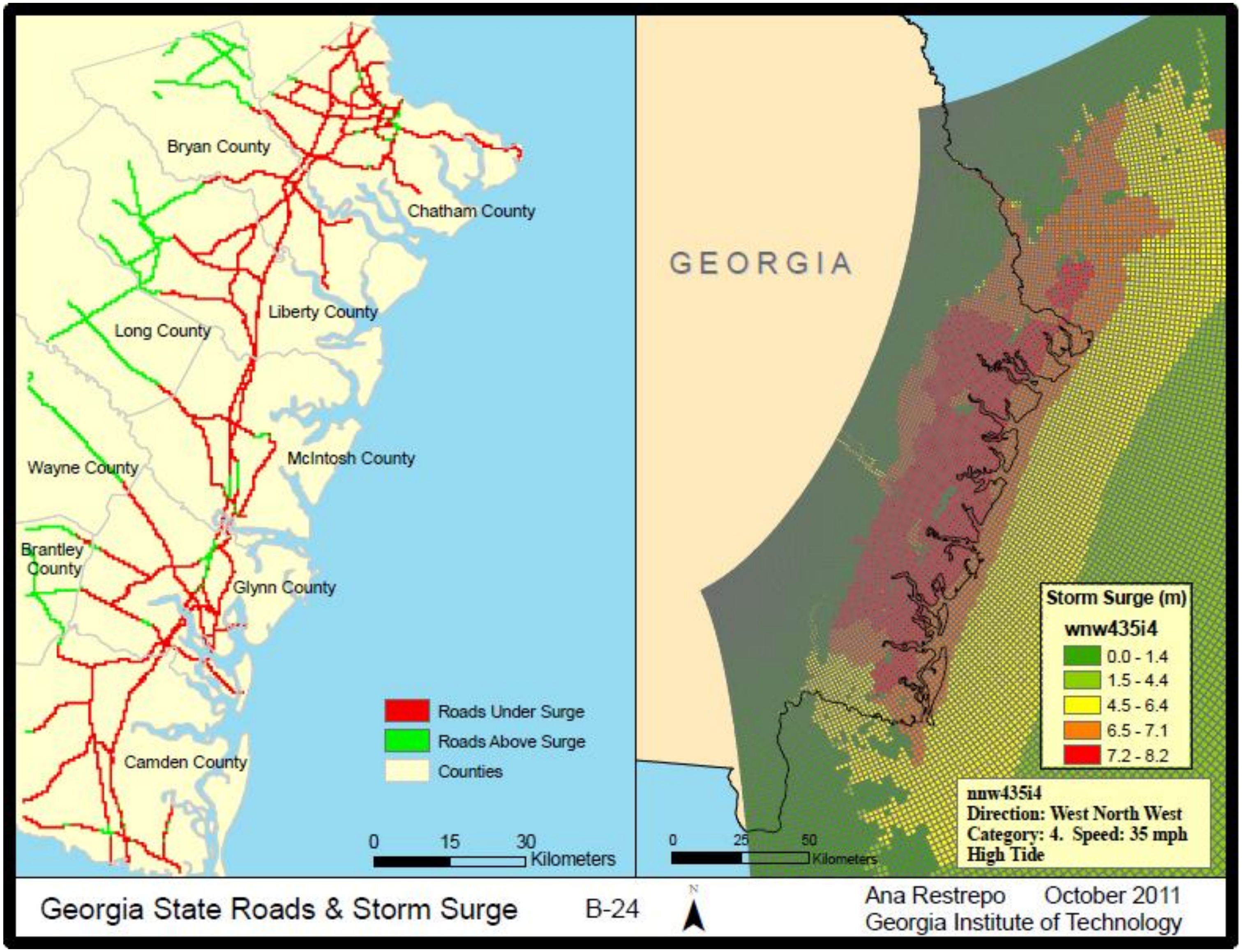

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw415i4
0.0
0.1 - 2.7
2.8 - 5.7
5.8 - 6.3
6.4 - 7.1
nnw415i4
Direction: West North West
Category: 4. Speed: 15 mph
High Tide
0 25 50 Kilometers
Georgia State Railroads
B-20
N
Ana Restrepo October 2011
Georgia Institute of Technology

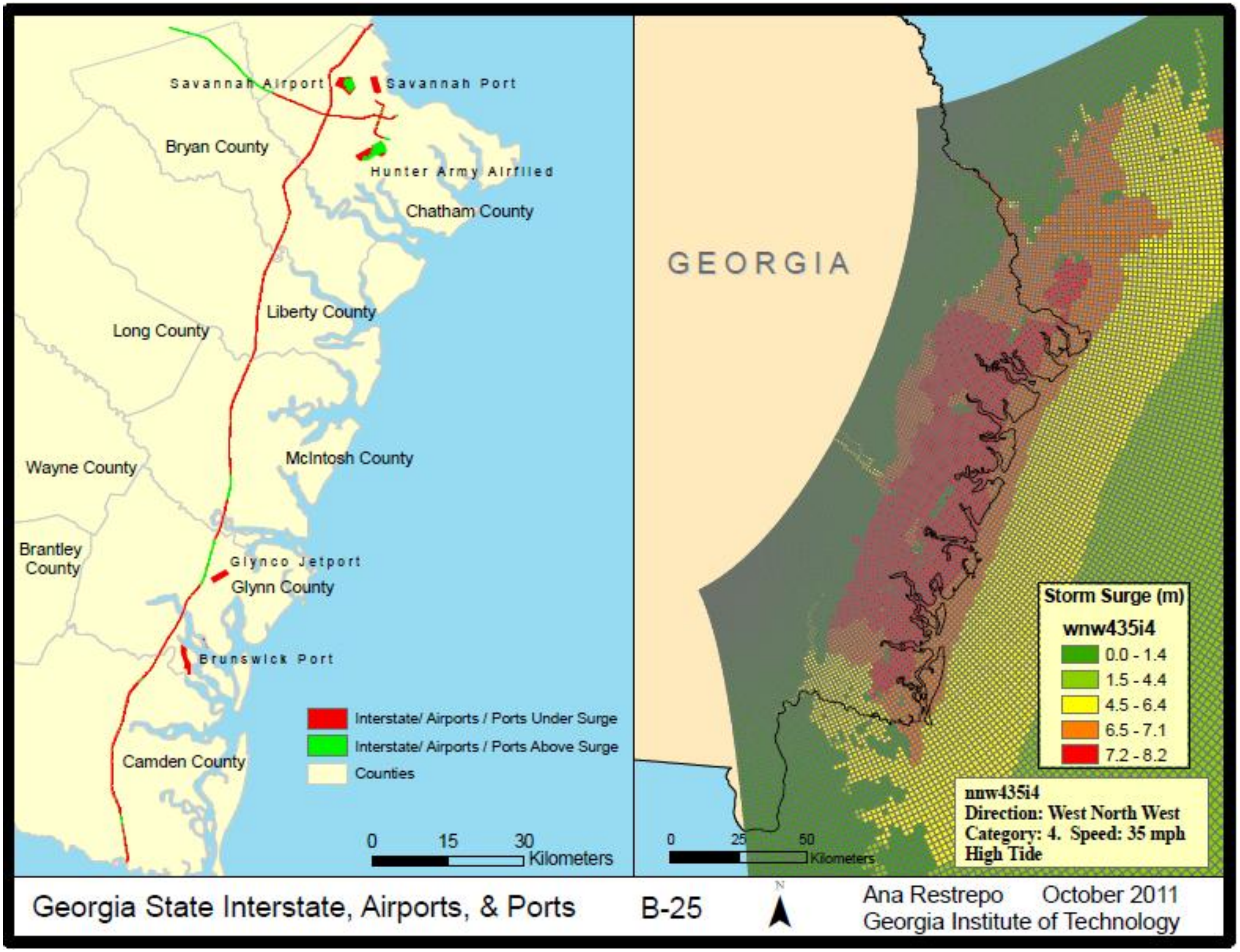

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw425i4
0.0
0.1 - 2.8
2.9 - 5.7
5.8 - 6.9
7.0 - 7.7
nnw425i4
Direction: West North West
Category: 4. Speed: 25 mph
High Tide
0 25 50 Kilometers
Georgia State Roads & Storm Surge
B-21
N
Ana Restrepo October 2011
Georgia Institute of Technology

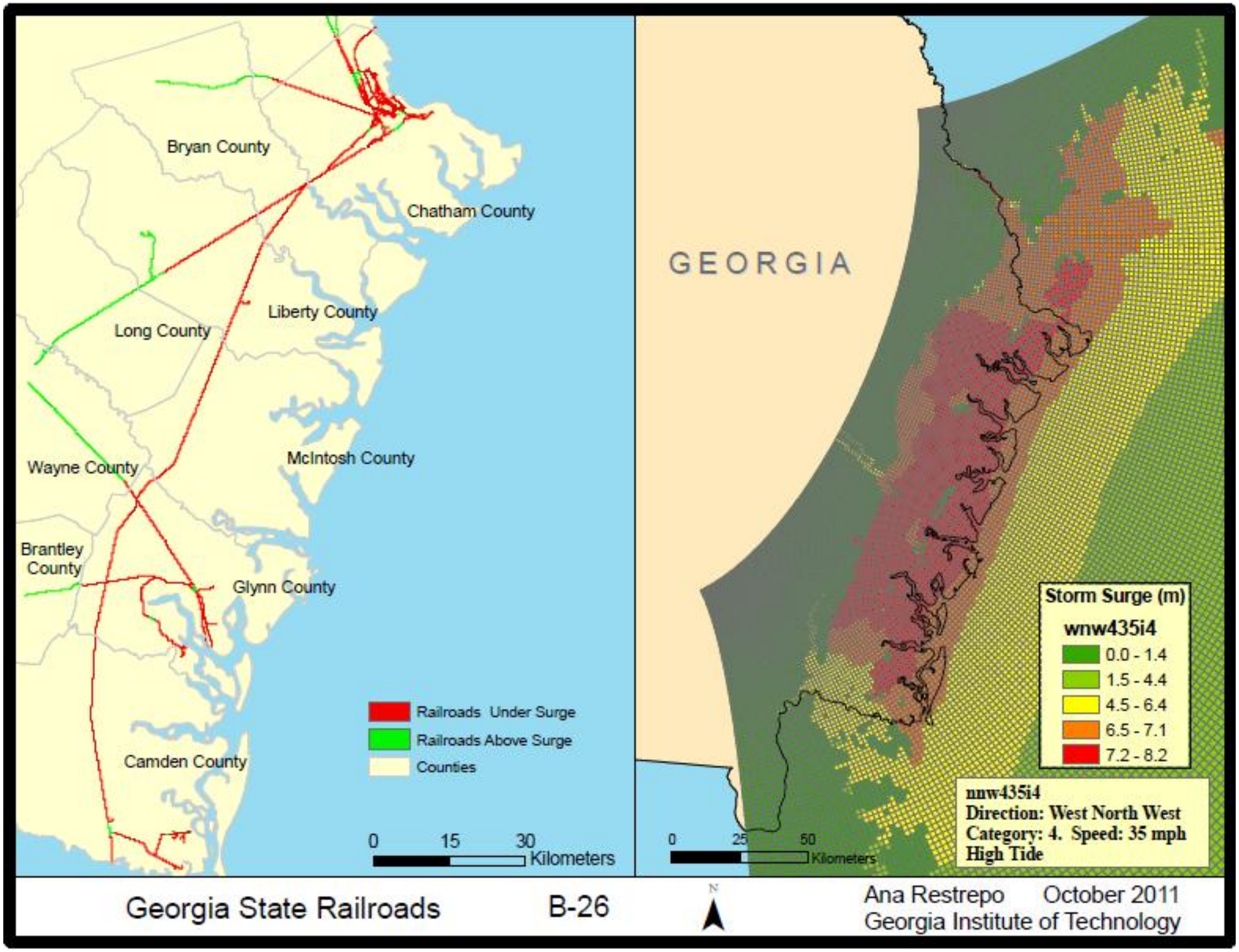

Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airports / Ports Under Surge
Interstate/ Airports / Ports Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw425i4
0.0
0.1 - 2.8
2.9 - 5.7
5.8 - 6.9
7.0 - 7.7
nnw425i4
Direction: West North West
Category: 4. Speed: 25 mph
High Tide
0 25 50 Kilometers
Georgia State Interstate, Airports, & Ports
B-22
N
Ana Restrepo October 2011
Georgia Institute of Technology

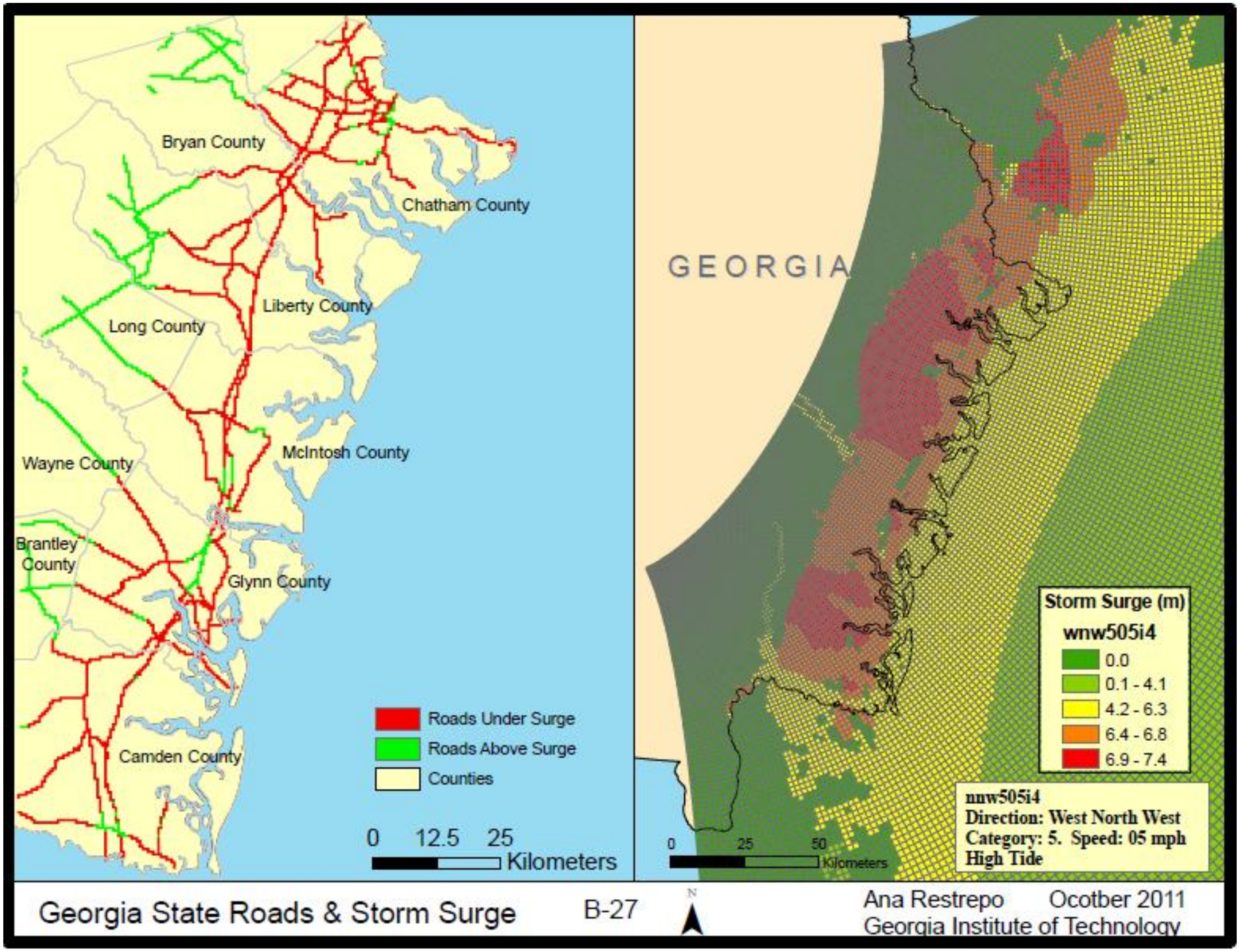


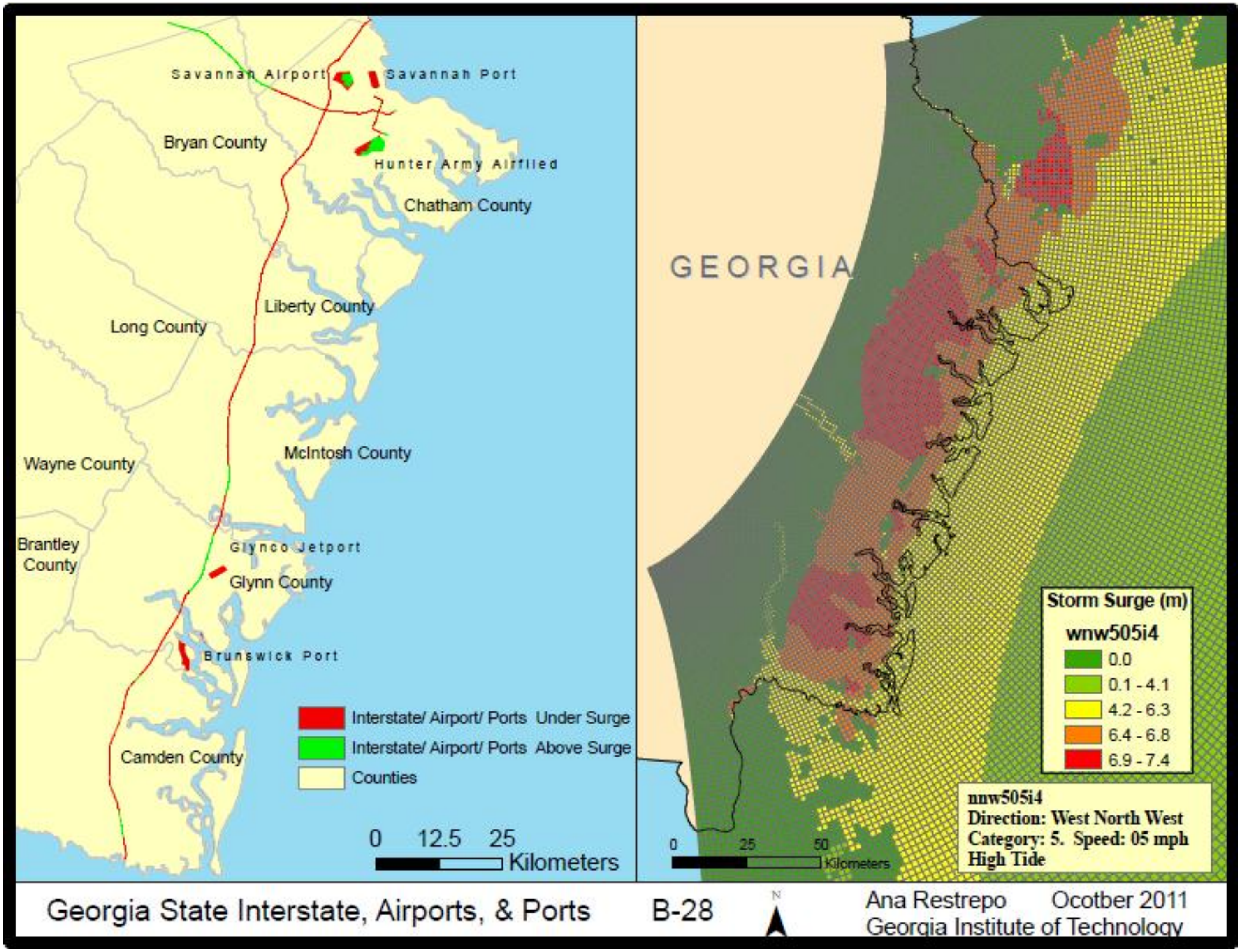
Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw425i4
0.0
0.1 - 2.8
2.9 - 5.7
5.8 - 6.9
7.0 - 7.7
nnw425i4
Direction: West North West
Category: 4. Speed: 25 mph
High Tide
0 25 50 Kilometers
Georgia State Railroads
B-23
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw435i4
0.0 - 1.4
1.5 - 4.4
4.5 - 6.4
6.5 - 7.1
7.2 - 8.2
nnw435i4
Direction: West North West
Category: 4. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Roads & Storm Surge
B-24
N
Ana Restrepo October 2011
Georgia Institute of Technology

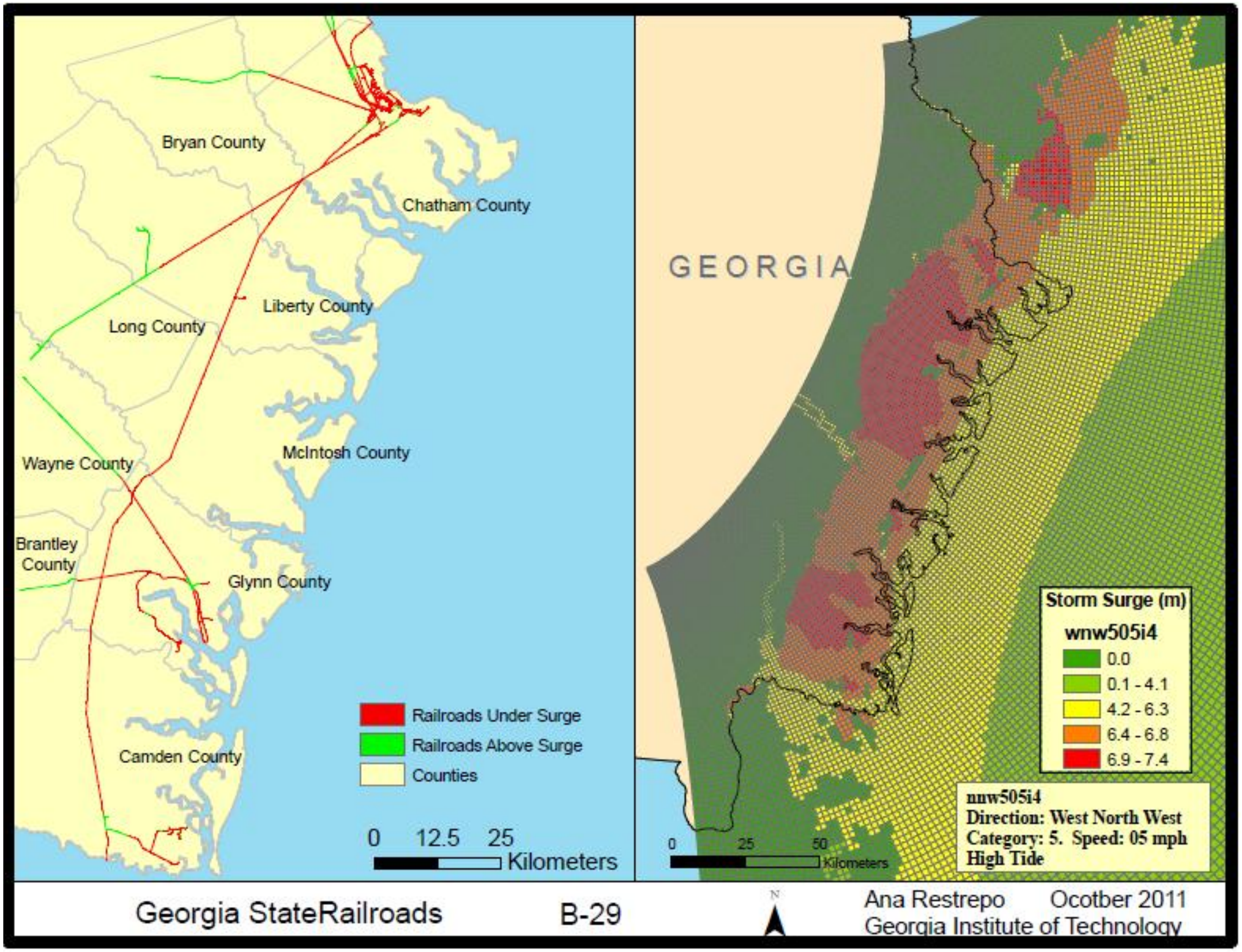

Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airports / Ports Under Surge
Interstate/ Airports / Ports Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw435i4
0.0 - 1.4
1.5 - 4.4
4.5 - 6.4
6.5 - 7.1
7.2 - 8.2
nnw435i4
Direction: West North West
Category: 4. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Interstate, Airports, & Ports
B-25
N
Ana Restrepo October 2011
Georgia Institute of Technology

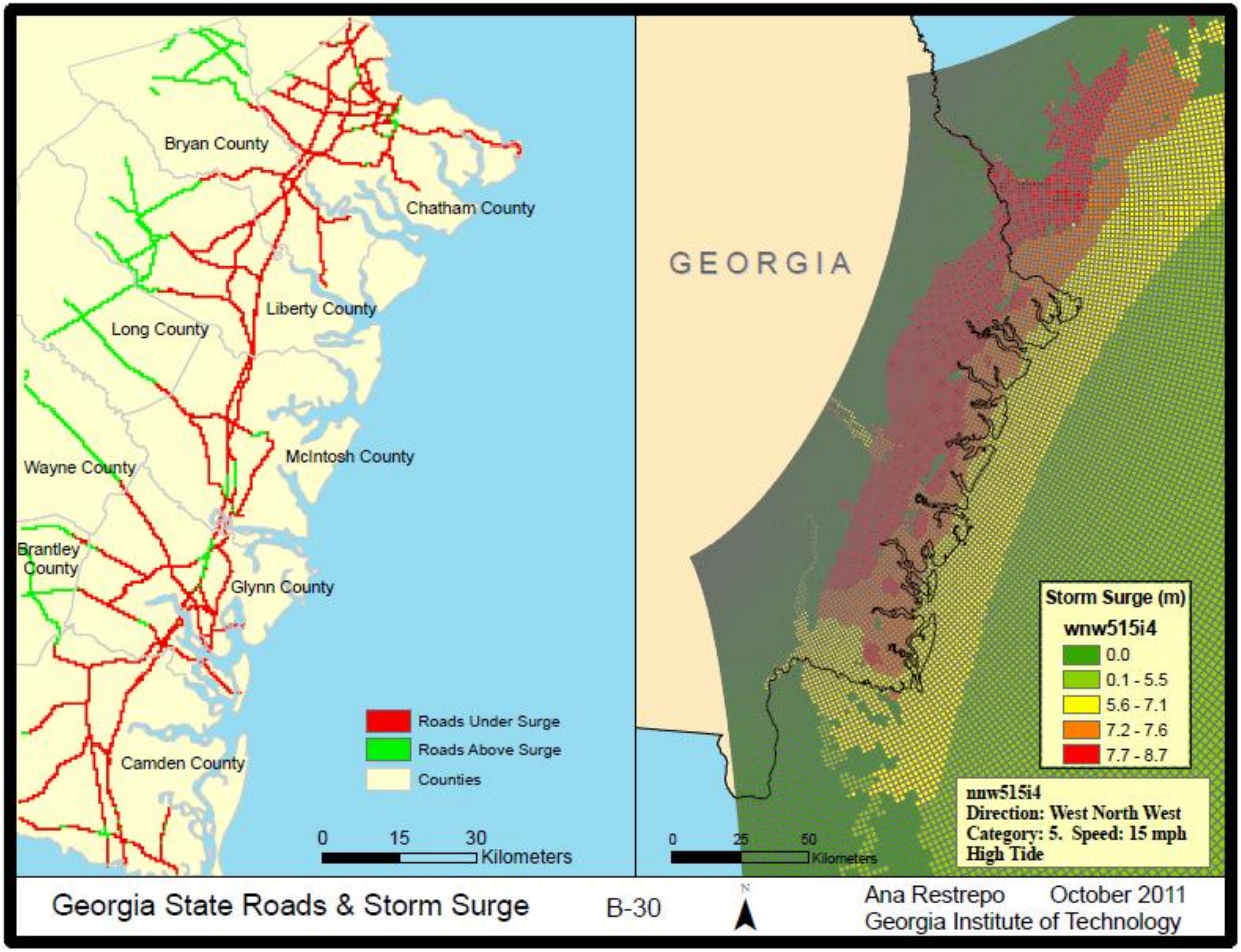

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw435i4
0.0 - 1.4
1.5 - 4.4
4.5 - 6.4
6.5 - 7.1
7.2 - 8.2
nnw435i4
Direction: West North West
Category: 4. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Railroads
B-26
N
Ana Restrepo October 2011
Georgia Institute of Technology

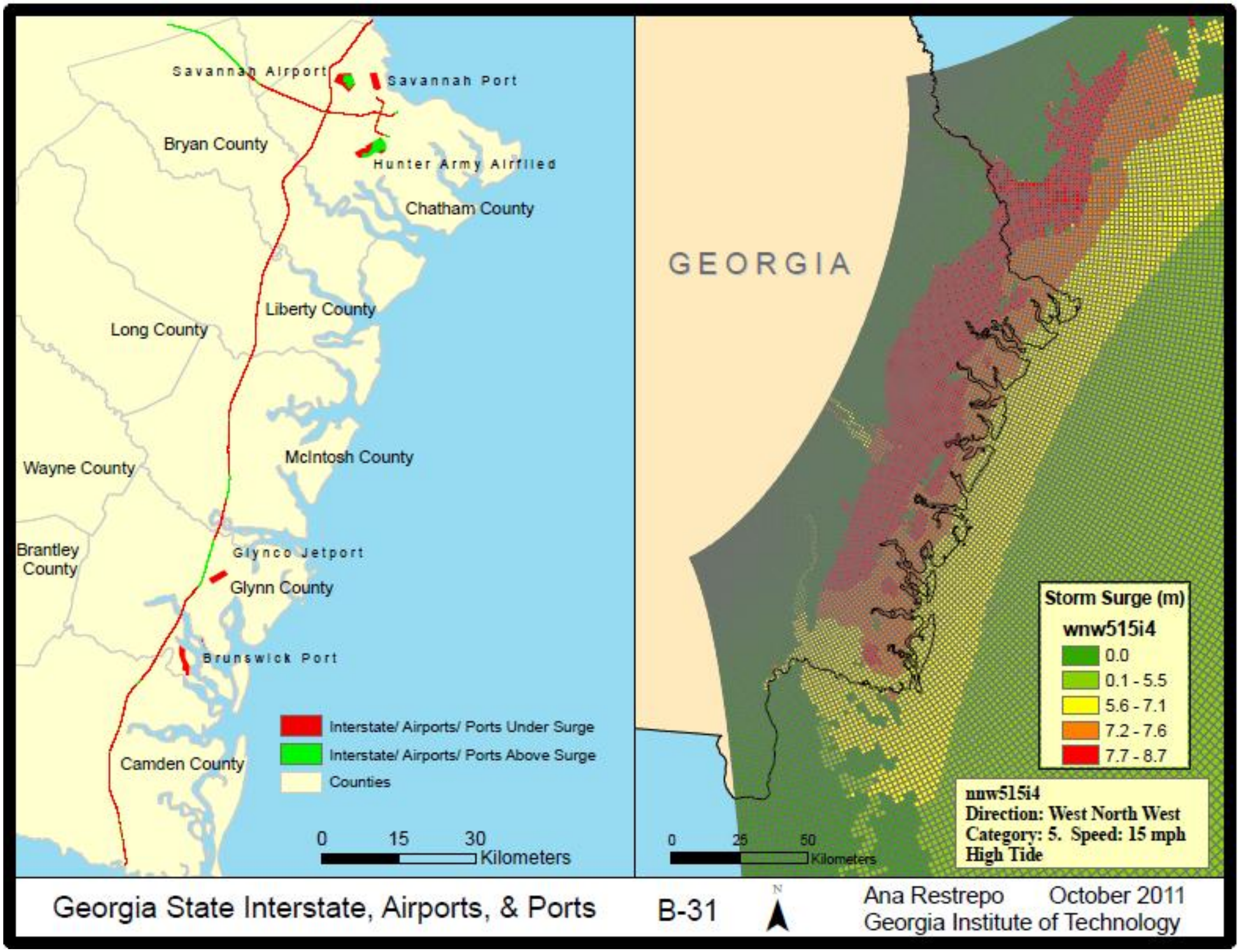

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw505i4
0.0
0.1 - 4.1
4.2 - 6.3
6.4 - 6.8
6.9 - 7.4
nnw505i4
Direction: West North West
Category: 5. Speed: 05 mph
High Tide
0 25 50 Kilometers
Georgia State Roads & Storm Surge
B-27
N
Ana Restrepo Octotber 2011
Georgia Institute of Technology

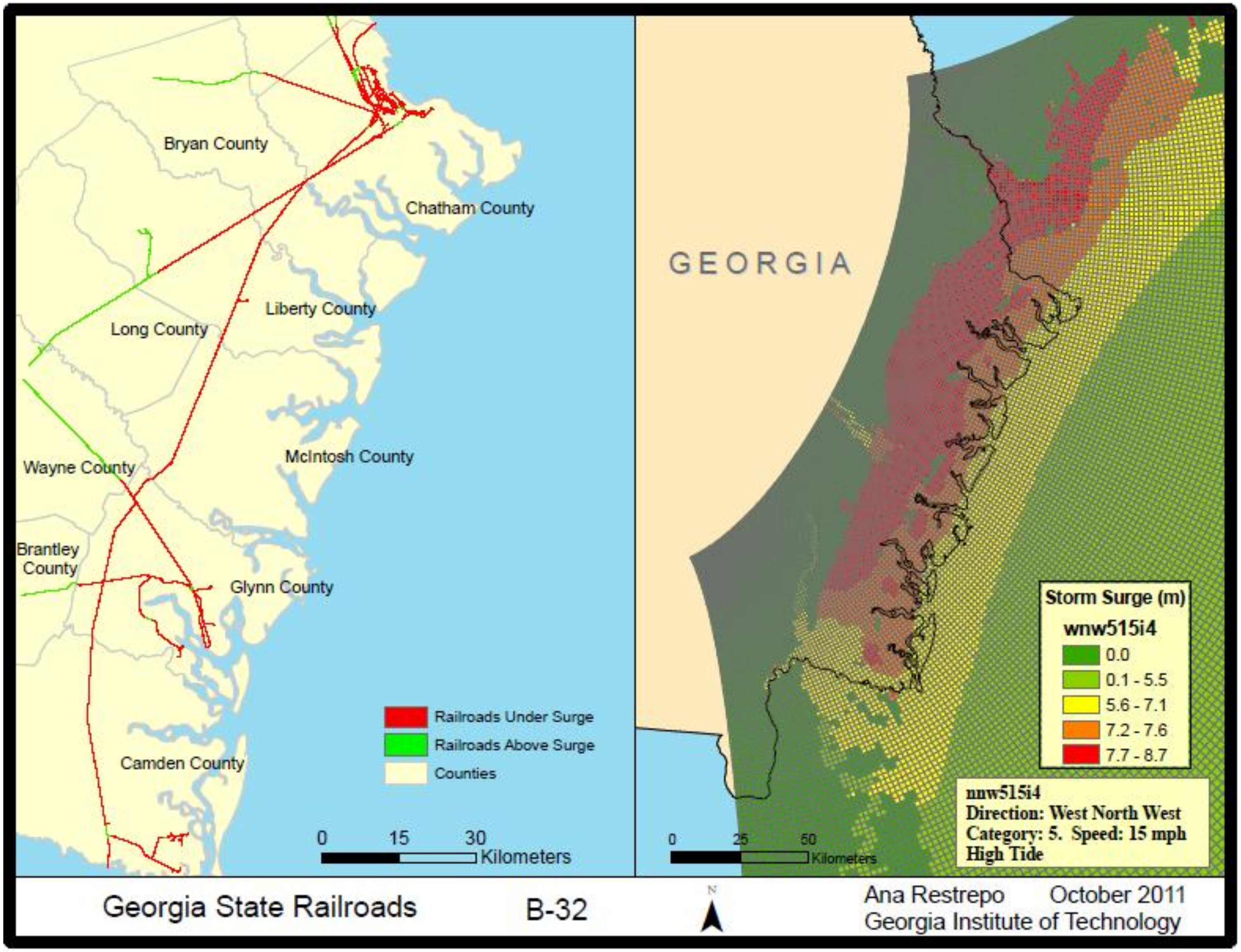


Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airport/ Ports Under Surge
Interstate/ Airport/ Ports Above Surge
Counties
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw505i4
0.0
0.1 - 4.1
4.2 - 6.3
6.4 - 6.8
6.9 - 7.4
nnw505i4
Direction: West North West
Category: 5. Speed: 05 mph
High Tide
0 25 50 Kilometers
Georgia State Interstate, Airports, & Ports
B-28
N
Ana Restrepo Ocotber 2011
Georgia Institute of Technology

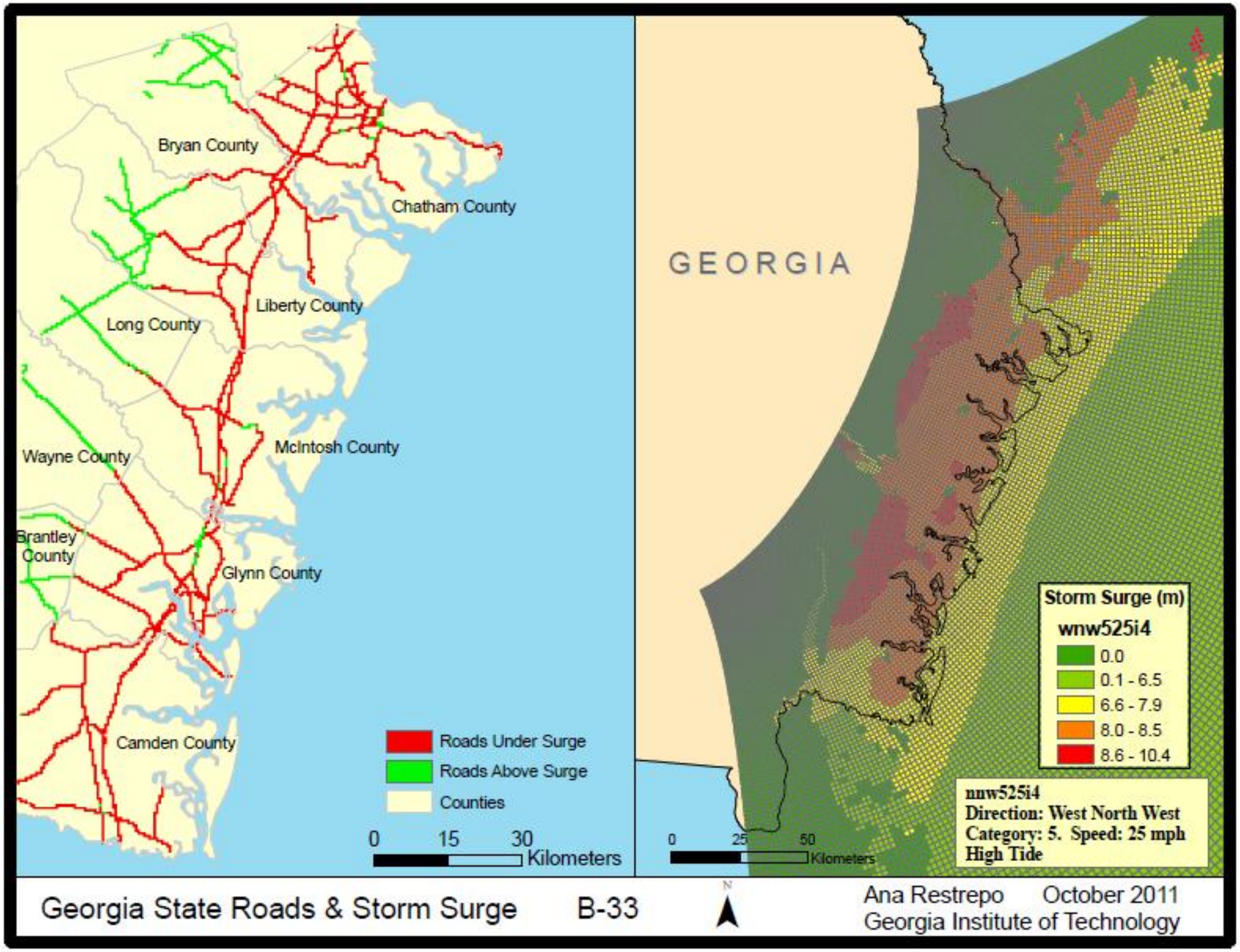

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 12.5 25 Kilometers
GEORGIA
Storm Surge (m)
wnw505i4
0.0
0.1 - 4.1
4.2 - 6.3
6.4 - 6.8
6.9 - 7.4
nnw505i4
Direction: West North West
Category: 5. Speed: 05 mph
High Tide
0 25 50 Kilometers
Georgia StateRailroads
B-29
N
Ana Restrepo Ocotber 2011
Georgia Institute of Technology

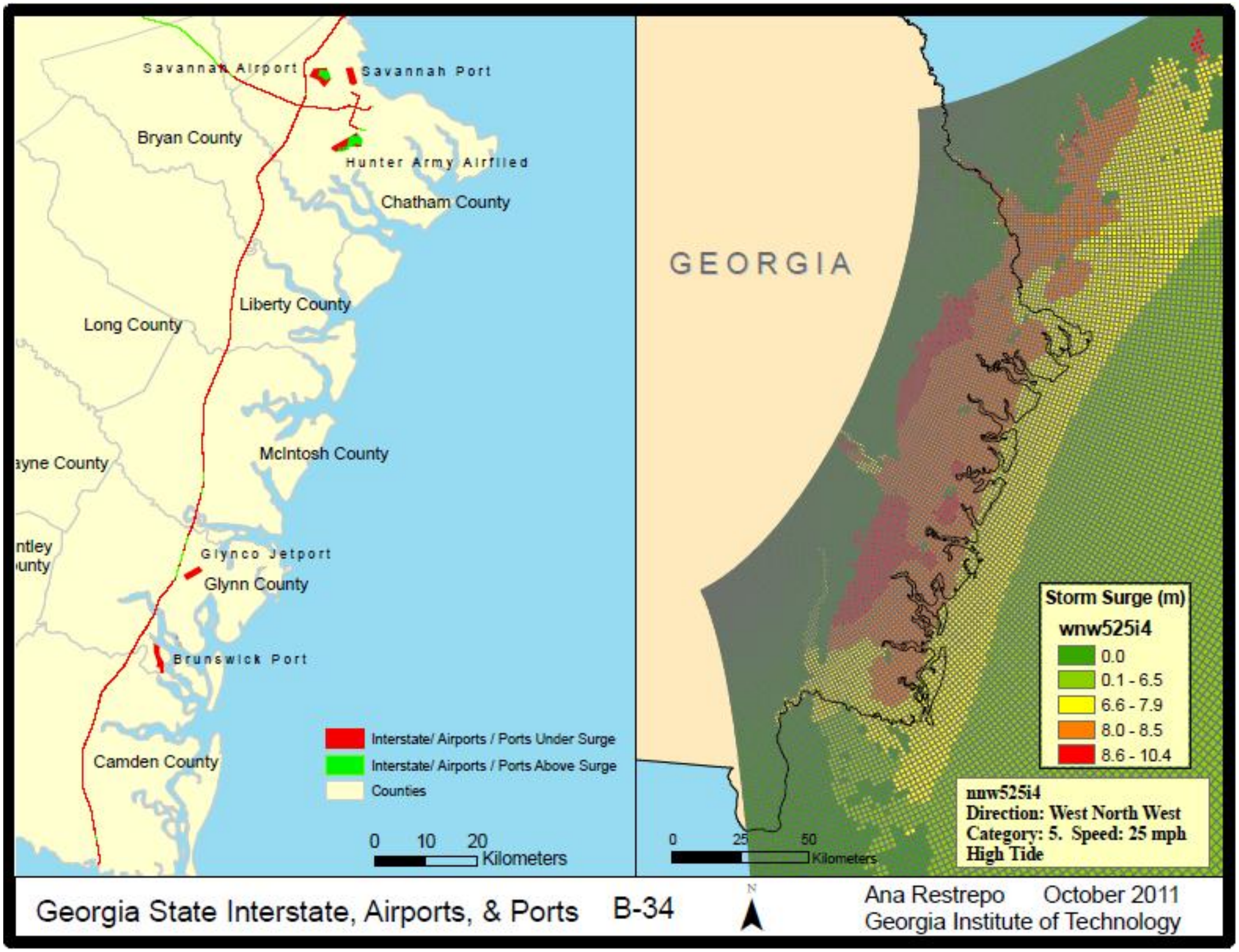

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw515i4
0.0
0.1 - 5.5
5.6 - 7.1
7.2 - 7.6
7.7 - 8.7
nnw515i4
Direction: West North West
Category: 5. Speed: 15 mph
High Tide
0 25 50 Kilometers
Georgia State Roads & Storm Surge
B-30
N
Ana Restrepo October 2011
Georgia Institute of Technology

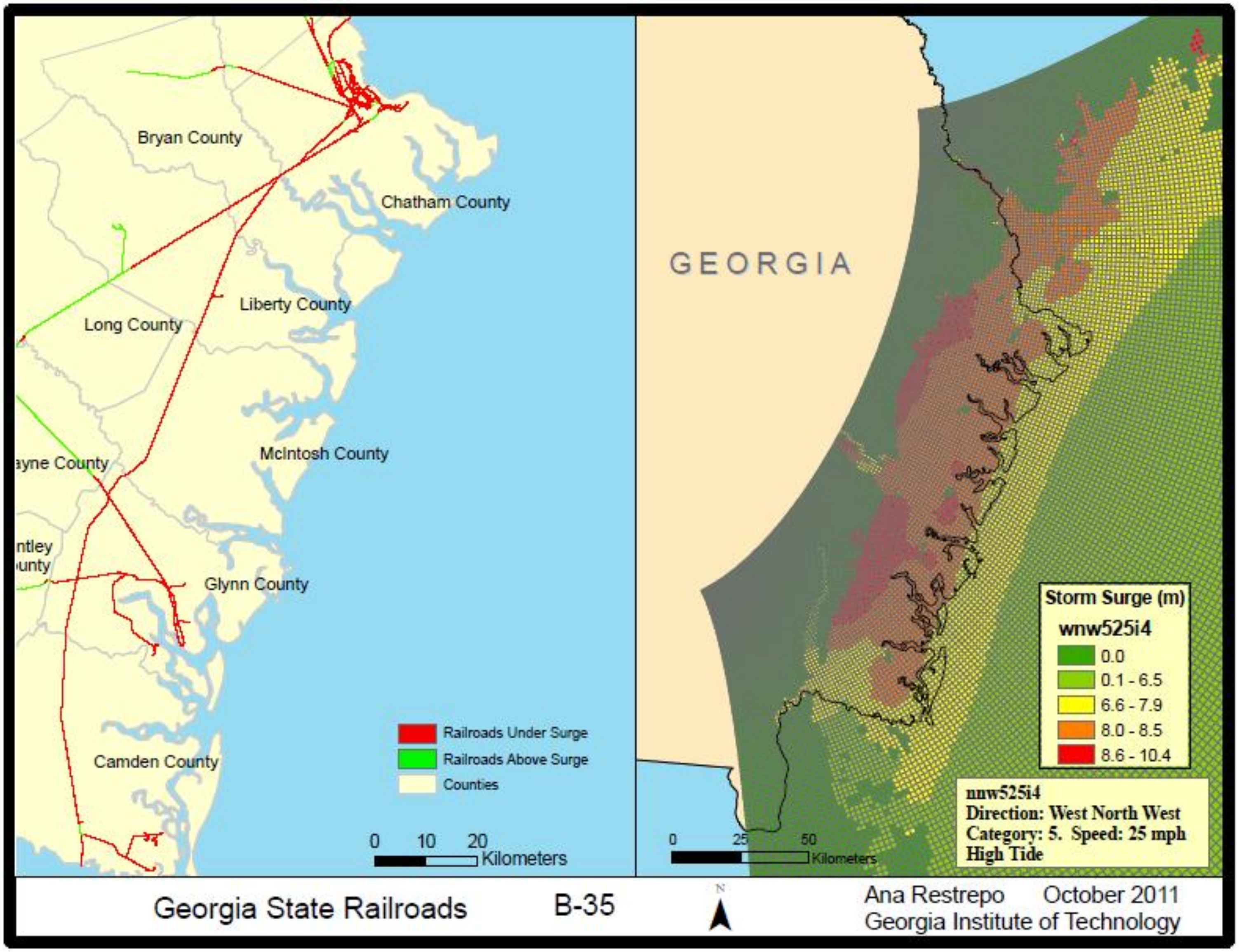

Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airports/ Ports Under Surge
Interstate/ Airports/ Ports Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw515i4
0.0
0.1 - 5.5
5.6 - 7.1
7.2 - 7.6
7.7 - 8.7
nnw515i4
Direction: West North West
Category: 5. Speed: 15 mph
High Tide
0 25 50 Kilometers
Georgia State Interstate, Airports, & Ports
B-31
N
Ana Restrepo October 2011
Georgia Institute of Technology

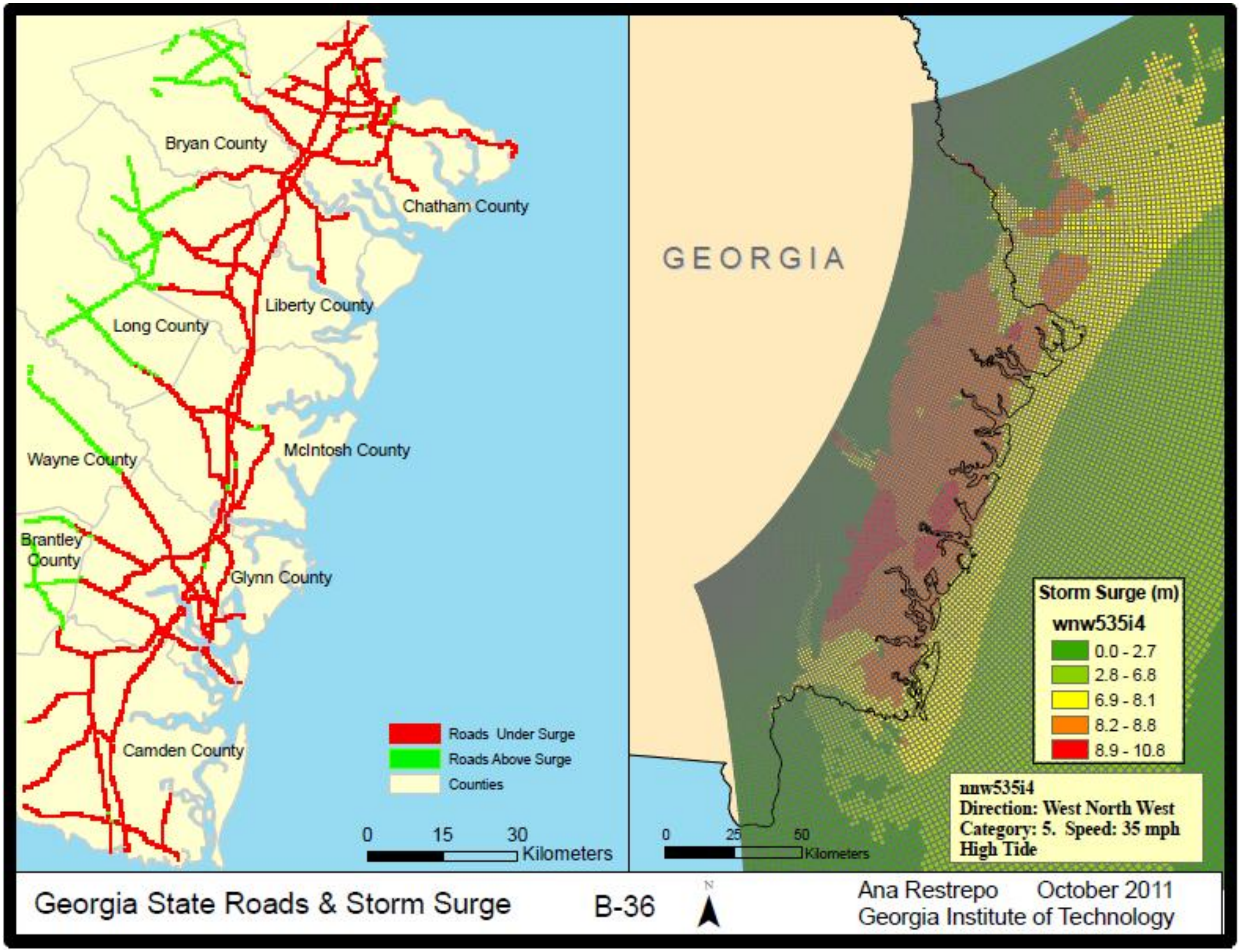


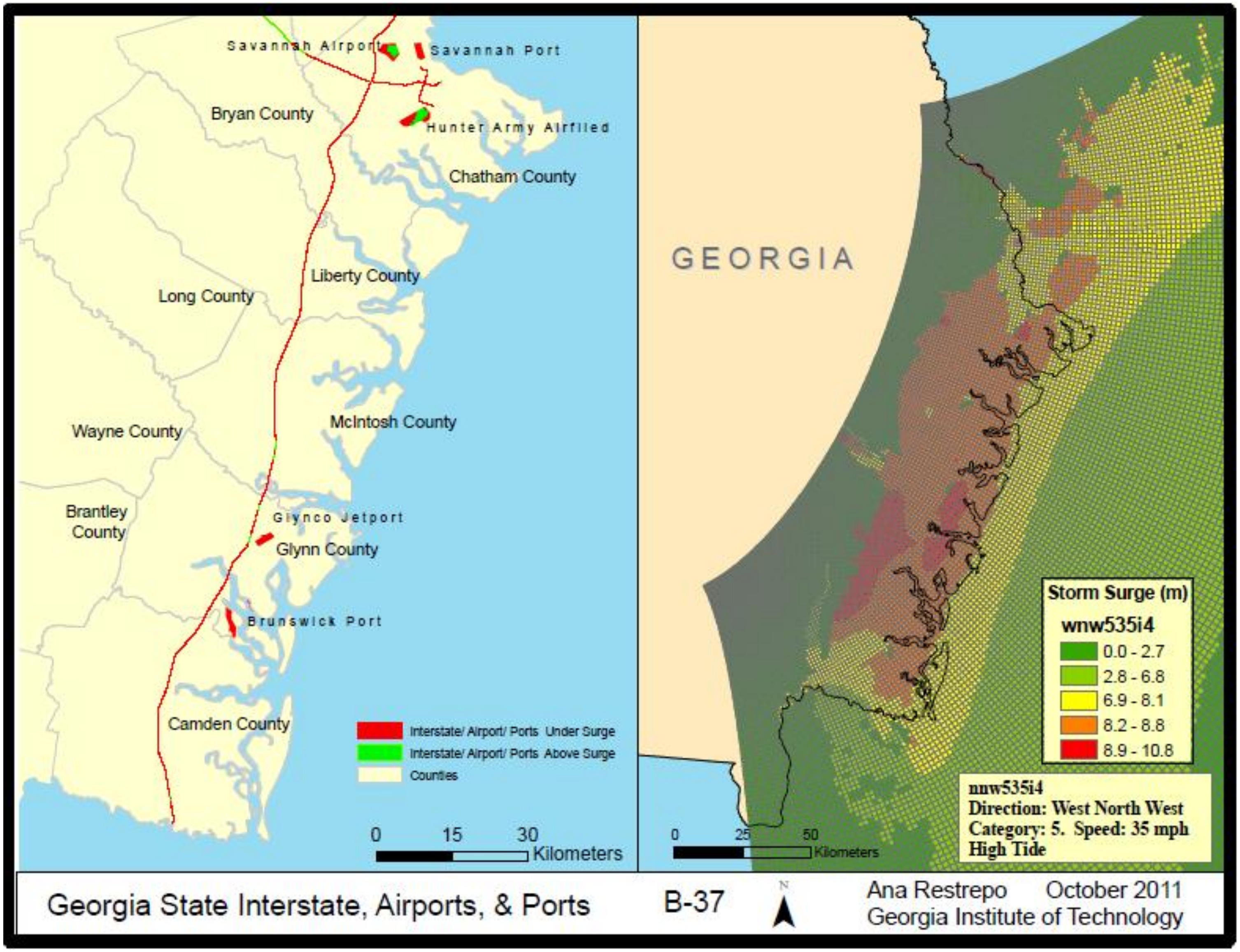
Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw515i4
0.0
0.1 - 5.5
5.6 - 7.1
7.2 - 7.6
7.7 - 8.7
nnw515i4
Direction: West North West
Category: 5. Speed: 15 mph
High Tide
0 25 50 Kilometers
Georgia State Railroads
B-32
N
Ana Restrepo October 2011
Georgia Institute of Technology

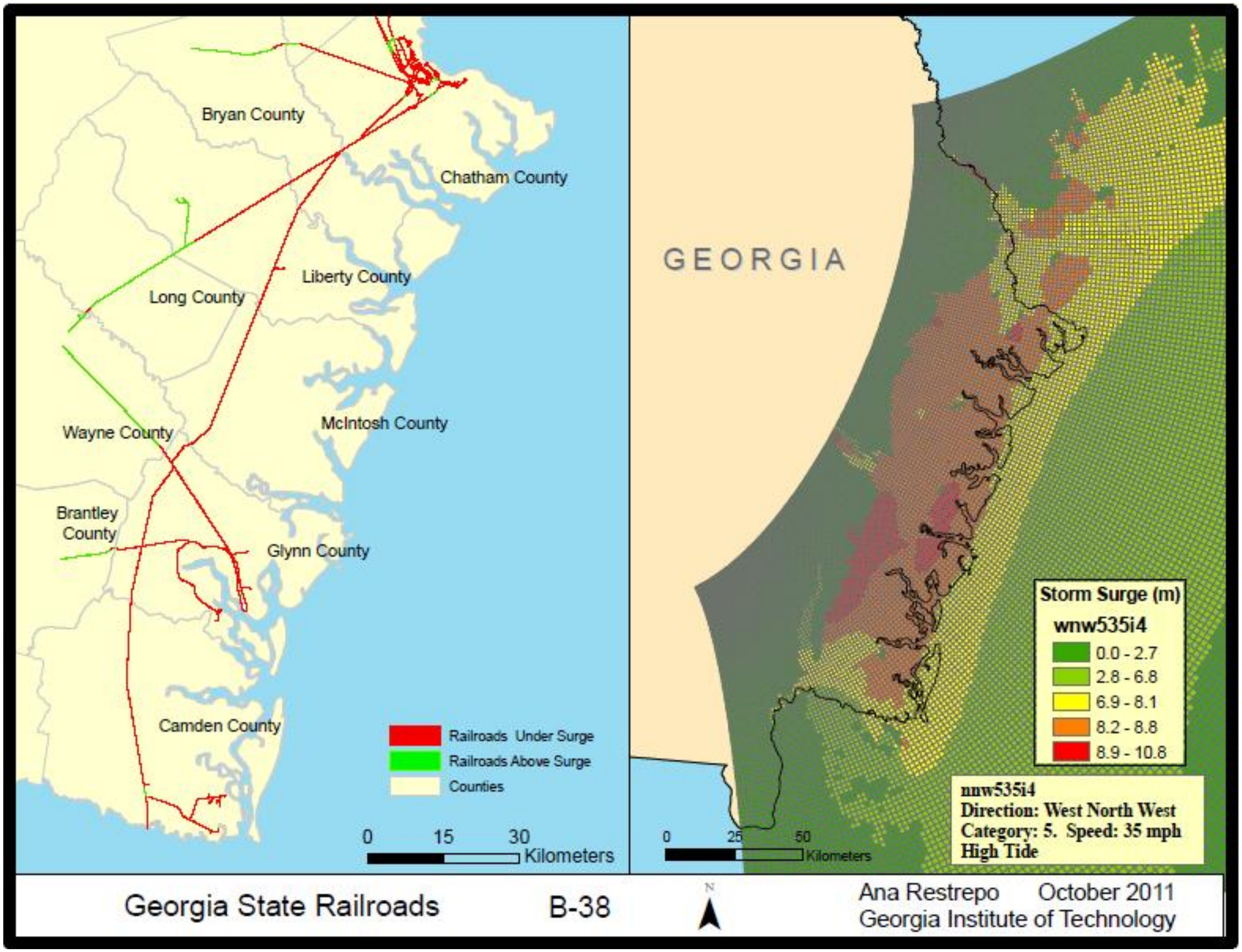

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw525i4
0.0
0.1 - 6.5
6.6 - 7.9
8.0 - 8.5
8.6 - 10.4
nnw525i4
Direction: West North West
Category: 5. Speed: 25 mph
High Tide
0 25 50 Kilometers
N
Georgia State Roads & Storm Surge B-33
Ana Restrepo October 2011
Georgia Institute of Technology

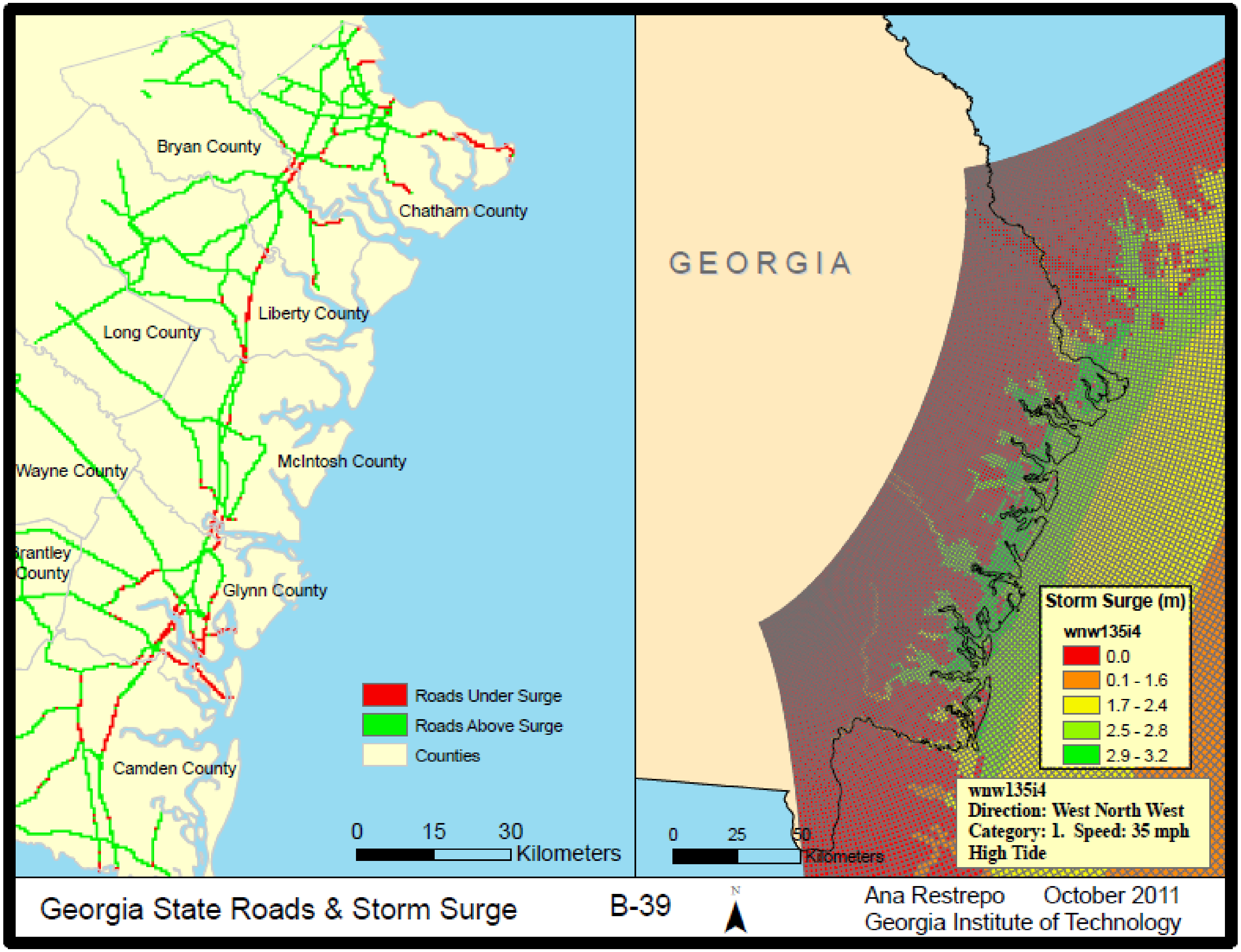

Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
ayne County
ntley
unty
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airports / Ports Under Surge
Interstate/ Airports / Ports Above Surge
Counties
0 10 20
Kilometers
GEORGIA
0 25 50
Kilometers
Storm Surge (m)
wnw525i4
0.0
0.1 - 6.5
6.6 - 7.9
8.0 - 8.5
8.6 - 10.4
nnw525i4
Direction: West North West
Category: 5. Speed: 25 mph
High Tide
Georgia State Interstate, Airports, & Ports
B-34
N
Ana Restrepo
October 2011
Georgia Institute of Technology

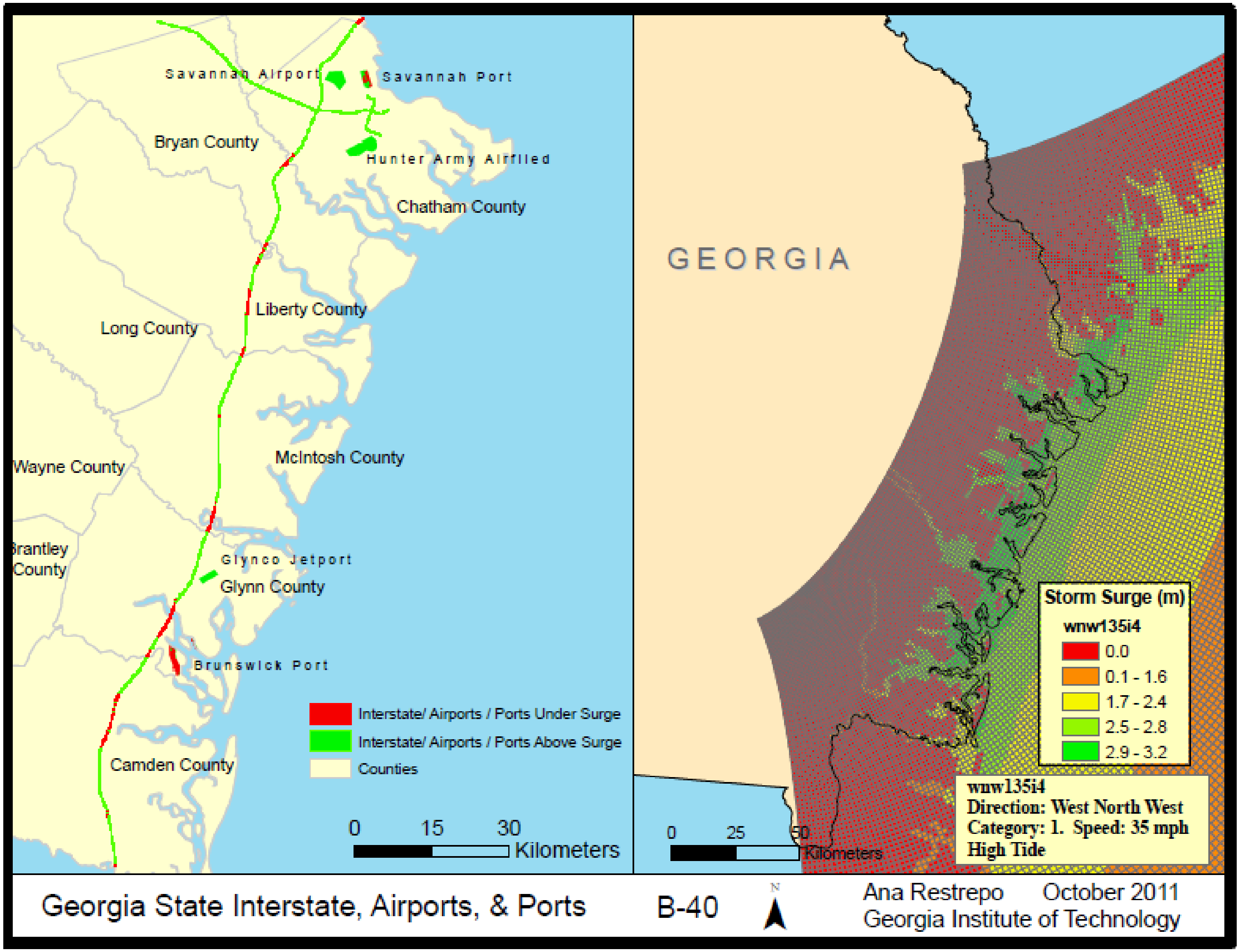

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
ayne County
ntley
unty
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 10 20 Kilometers
GEORGIA
0 25 50 Kilometers
Storm Surge (m)
wnw525i4
0.0
0.1 - 6.5
6.6 - 7.9
8.0 - 8.5
8.6 - 10.4
nnw525i4
Direction: West North West
Category: 5. Speed: 25 mph
High Tide
Georgia State Railroads
B-35
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw535i4
0.0 - 2.7
2.8 - 6.8
6.9 - 8.1
8.2 - 8.8
8.9 - 10.8
nnw535i4
Direction: West North West
Category: 5. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Roads & Storm Surge
B-36
Ana Restrepo October 2011
Georgia Institute of Technology


Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
Wayne County
McIntosh County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airport/ Ports Under Surge
Interstate/ Airport/ Ports Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw535i4
0.0 - 2.7
2.8 - 6.8
6.9 - 8.1
8.2 - 8.8
8.9 - 10.8
nnw535i4
Direction: West North West
Category: 5. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Interstate, Airports, & Ports
B-37
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
Liberty County
Long County
Wayne County
McIntosh County
Brantley
County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 15 30
Kilometers
GEORGIA
Storm Surge (m)
wnw535i4
0.0 - 2.7
2.8 - 6.8
6.9 - 8.1
8.2 - 8.8
8.9 - 10.8
nnw535i4
Direction: West North West
Category: 5. Speed: 35 mph
High Tide
0 25 50
Kilometers
Georgia State Railroads
B-38
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw135i4
0.0
0.1 - 1.6
1.7 - 2.4
2.5 - 2.8
2.9 - 3.2
wnw135i4
Direction: West North West
Category: 1. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Roads & Storm Surge
B-39
N
Ana Restrepo October 2011
Georgia Institute of Technology


Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airports / Ports Under Surge
Interstate/ Airports / Ports Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw135i4
0.0
0.1 - 1.6
1.7 - 2.4
2.5 - 2.8
2.9 - 3.2
wnw135i4
Direction: West North West
Category: 1. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Interstate, Airports, & Ports
B-40
N
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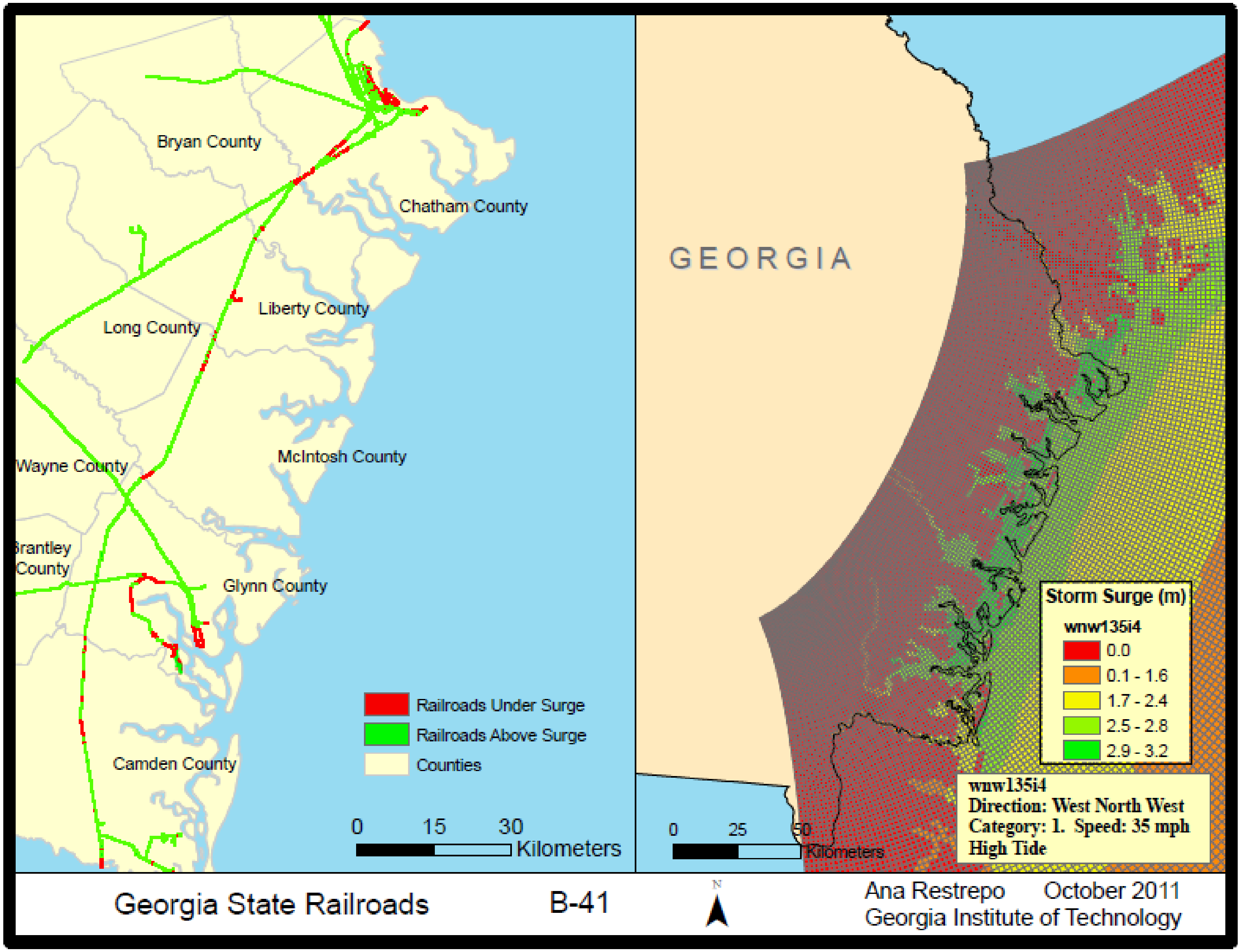
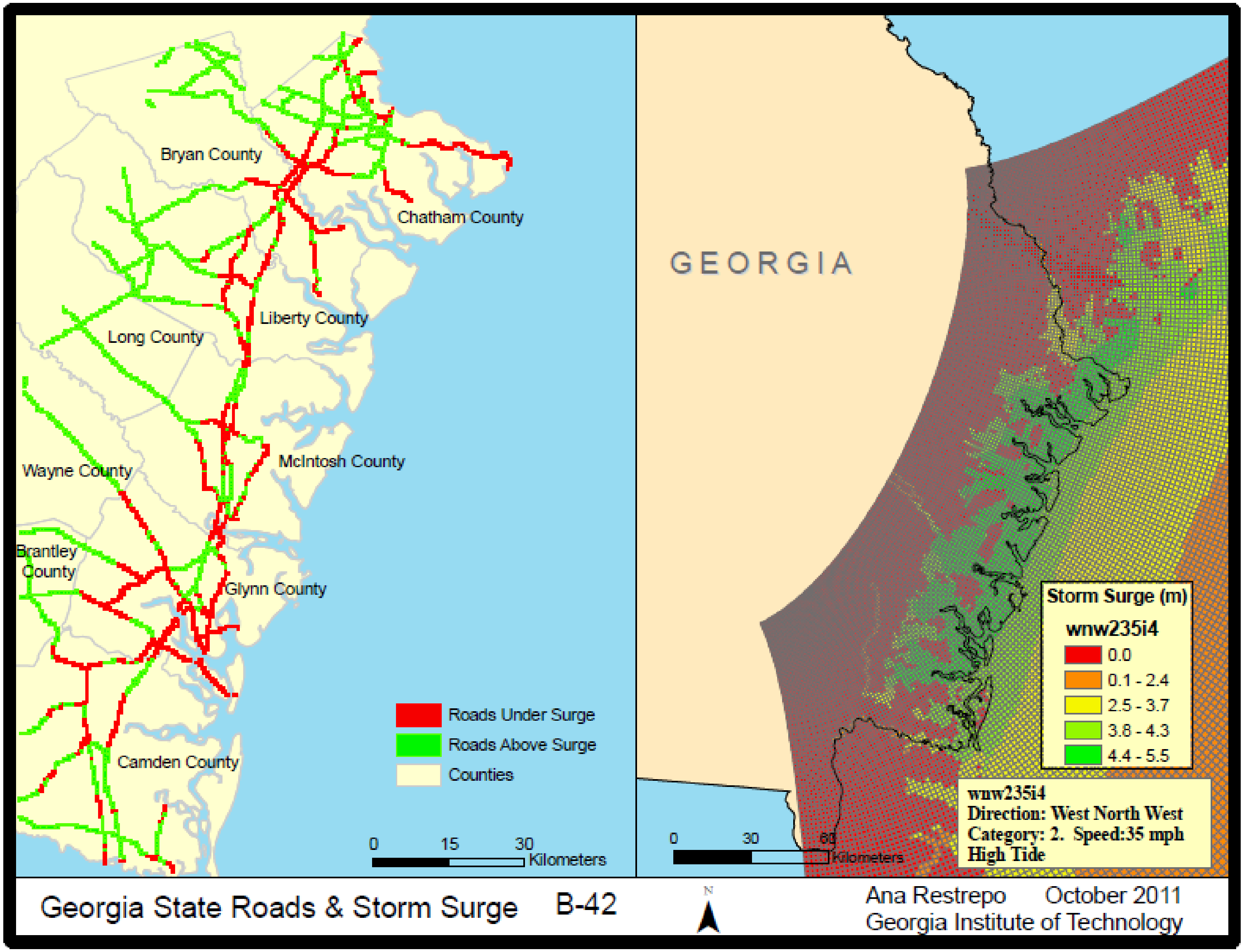
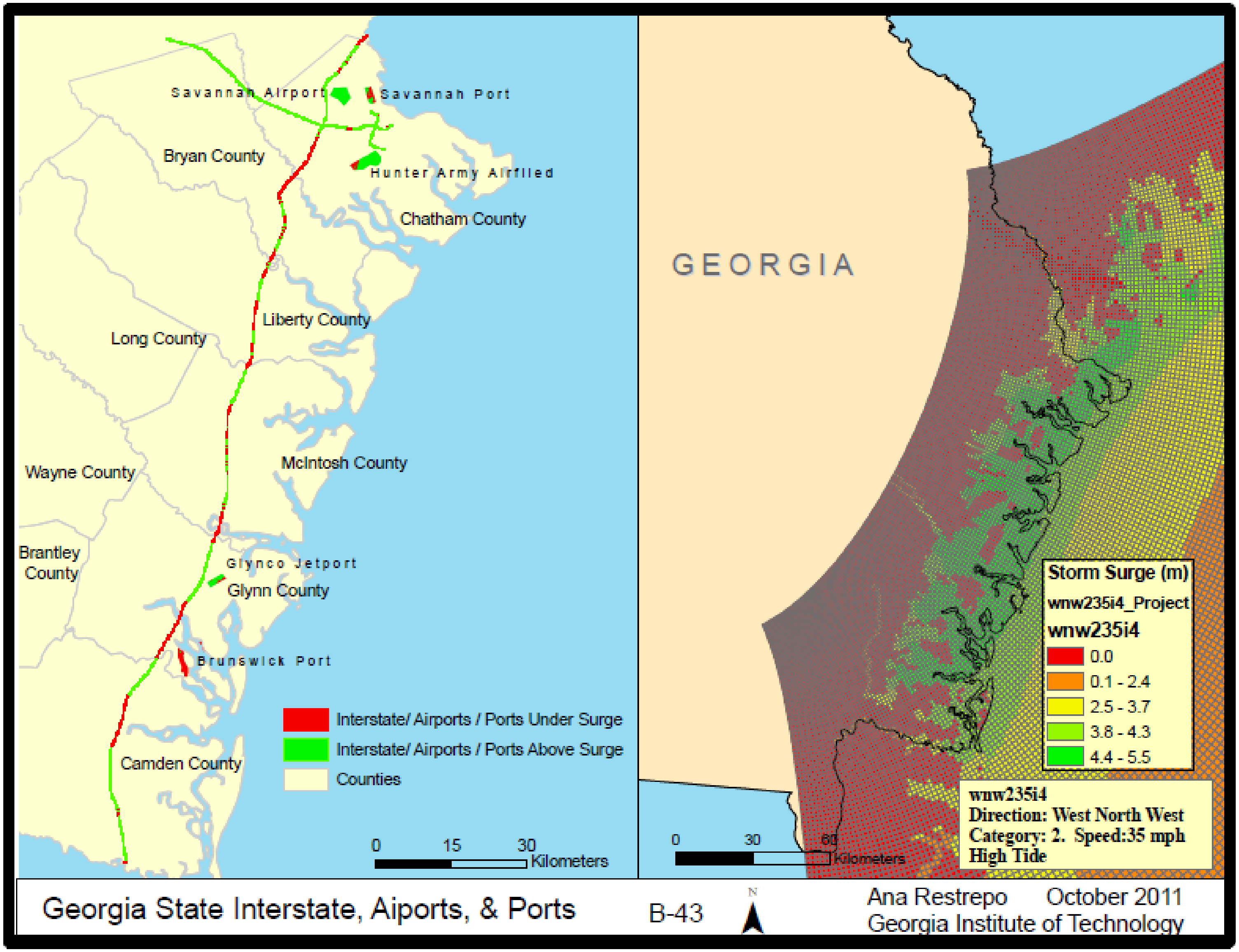
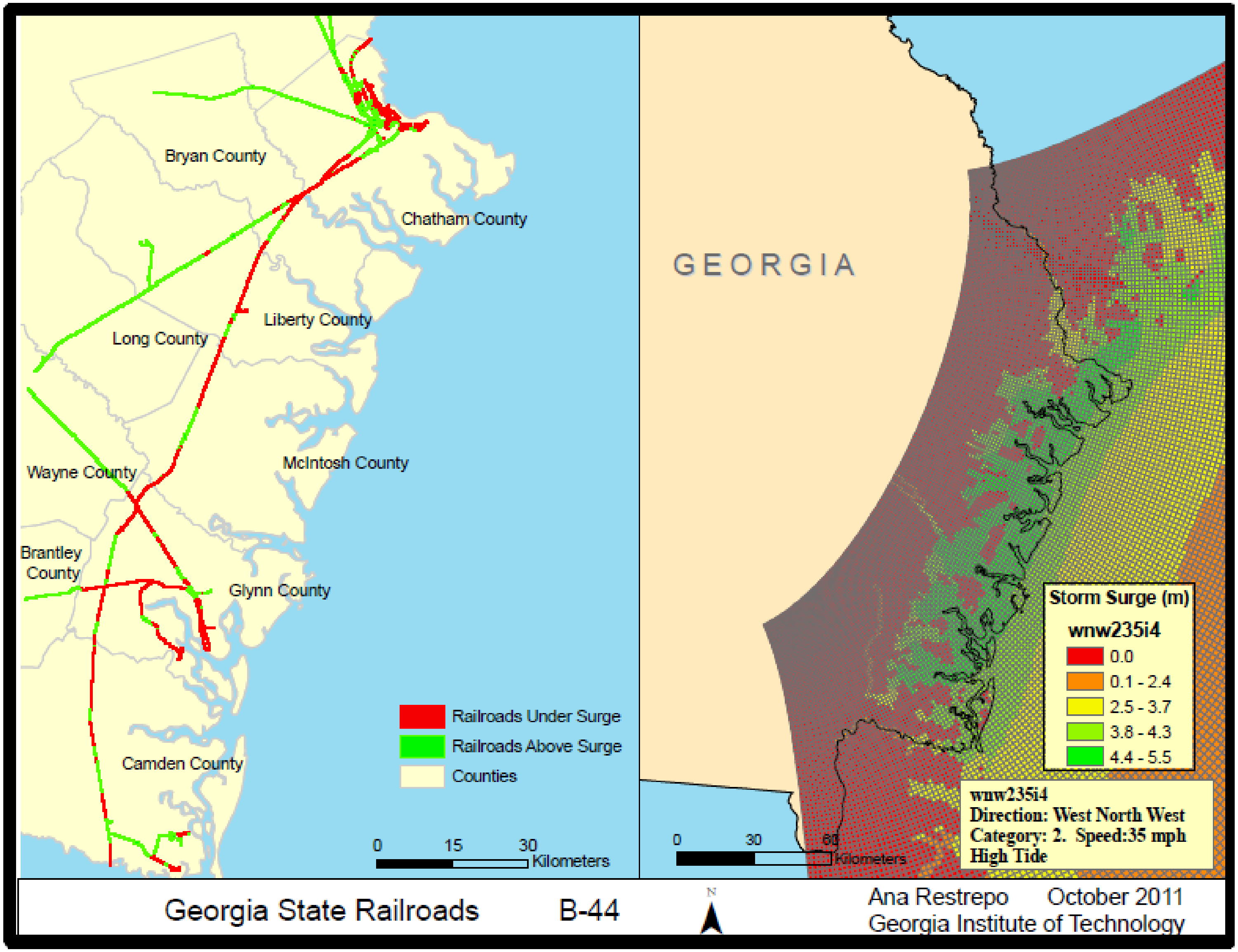

Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw135i4
0.0
0.1 - 1.6
1.7 - 2.4
2.5 - 2.8
2.9 - 3.2
wnw135i4
Direction: West North West
Category: 1. Speed: 35 mph
High Tide
0 25 50 Kilometers
Georgia State Railroads
B-41
N
Ana Restrepo October 2011
Georgia Institute of Technology


Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Roads Under Surge
Roads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
0 30 60 Kilometers
Storm Surge (m)
wnw235i4
0.0
0.1 - 2.4
2.5 - 3.7
3.8 - 4.3
4.4 - 5.5
wnw235i4
Direction: West North West
Category: 2. Speed:35 mph
High Tide
Georgia State Roads & Storm Surge B-42
N
Ana Restrepo October 2011
Georgia Institute of Technology



Savannah Airport
Savannah Port
Bryan County
Hunter Army Airfiled
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynco Jetport
Glynn County
Brunswick Port
Camden County
Interstate/ Airports / Ports Under Surge
Interstate/ Airports / Ports Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw235i4_Project
wnw235i4
0.0
0.1 - 2.4
2.5 - 3.7
3.8 - 4.3
4.4 - 5.5
wnw235i4
Direction: West North West
Category: 2. Speed:35 mph
High Tide
0 30 60 Kilometers
Georgia State Interstate, Aiports, & Ports
B-43
N
Ana Restrepo October 2011
Georgia Institute of Technology



Bryan County
Chatham County
Liberty County
Long County
McIntosh County
Wayne County
Brantley County
Glynn County
Camden County
Railroads Under Surge
Railroads Above Surge
Counties
0 15 30 Kilometers
GEORGIA
Storm Surge (m)
wnw235i4
0.0
0.1 - 2.4
2.5 - 3.7
3.8 - 4.3
4.4 - 5.5
0 30 60 Kilometers
wnw235i4
Direction: West North West
Category: 2. Speed:35 mph
High Tide
Georgia State Railroads
B-44
N
Ana Restrepo
October 2011
Georgia Institute of Technology

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